KARAKTERISASI MATERIAL KOMPOSIT JERAMI-EPOKSI YANG DIBUAT DENGAN PROSES VACUUM BAG

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Pembimbing I

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ABSTRAK

Pemanfaatan material komposit pada saat ini semakin berkembang, penggunaannya mulai dari peralatan rumah tangga, furnitur sampai ke sektor perindustrian. Material komposit memiliki keunggulan yaitu densitas yang rendah, tahan korosi dan proses pembuatannya yang sederhana. Dalam penelitian ini dipilih serat jerami sebagai penguat pada material komposit ini karna mudah didapatkan dan dimaksudkan juga untuk pemanfaatan jerami yang biasanya hanya digunakan sebagai bahan pupuk atau makanan ternak, bahkan banyak yang dibiarkan membusuk atau dibakar sehingga menjadi polusi.

Objek pada penelitian ini adalah membuat dan melakukan serangkaian pengujian pada material komposit berserat jerami dengan variasi panjang serat 20 mm dan 30 mm yang menggunakan resin epoksi sebagai pengikat dan pembuatan dengan metode *vacuum bag moulding*. Serangkaian pengujian dilakukan untuk mengetahui kekuatan dari material tersebut dan dilakukan juga perhitungan ulang fraksi volume sebenarnya untuk dibandingkan dengan fraksi volume awal 50 % jerami.

Hasil pengujian menunjukan bahwa material komposit dengan panjang serat jerami 20 mm memiliki kekuatan tarik rata-rata 18,99 MPa dan kekuatan bending rata-rata 98,05 MPa, sedangkan untuk material komposit dengan panjang serat jerami 30 mm memiliki kekuatan tarik rata-rata 19,68 MPa dan kekuatan bending rata-rata 98,86 MPa. Fraksi volume setelah material komposit jadi adalah 35% jerami.

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Penulis

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BAB I
PENDAHULUAN

1.1 Latar Belakang

Kebutuhan komponen dengan kemampuan struktural, ringan serta kuat mengalami peningkatan yang cukup signifikan. Hal ini telah mendorong perkembangan material baru yang disebut material komposit. Komposit adalah gabungan dari dua atau lebih material, pada umumnya tersusun dari material pengikat (*matrik*) dan material penguat yang disebut juga material pengisi (*filler*). Serat adalah salah satu material pengisi yang paling sering digunakan. Serat yang digunakan dapat berupa serat alami ataupun serat sintetis.

Sealin memiliki kemampuan struktural, ringan dan kuat, material yang ramah lingkungan juga merupakan tuntutan teknologi sekarang ini. Salah satu material yang diharapkan mampu memenuhi hal tersebut adalah material komposit dengan material pengisi serat alam. Keunggulan yang dimiliki oleh serat alam yaitu densitas yang rendah, mudah didapatkan, harga lebih murah, ramah lingkungan, dan tidak membahayakan bagi kesehatan.

Dalam penelitian ini menggunakan *filler* serat jerami padi, tujuannya agar meningkatkan fungsu guna dari serat ini. Jenis pengikat yang digunakan adalah resin epoksi. Resin epoksi

merupakan salah satu resin termoset yang mudah diperoleh dan digunakan masyarakat umum maupun industri skala kecil maupun besar. Resin ini juga mempunyai kemampuan berikatan dengan bahan lain yang baik sekali.

Banyak cara untuk membuat material komposit salah satu cara yang digunakan yaitu dengan proses *vacuum bag moulding*. Proses ini melibatkan ruang vakum/kedap udara dan didalamnya ditempatkan cetakan sehingga dalam ruang vakum tersebut dihasilkan temperatur dan tekanan yang dibutuhkan untuk proses pembuatan komposit yang lebih baik.

Tujuan akhir dari pembuatan material komposit ini adalah membuat suatu material baru yang memiliki kemampuan baik. Untuk mengetahui kemampuan dari material komposit tersebut maka dilakukan karakterisasi. Karakterisasi yang dilakukan adalah dengan melakukan pengujian mekanik.

1.2 Perumusan Masalah

Perumusan masalah dari tugas akhir ini dimana pada komposit berbasis serat jerami yang disusun secara lurus dan matrik resin epoksi sebagai pembentuk material komposit, dengan adanya penambahan variasi panjang serat yaitu :

- Bagaimanakah proses pabrikasi yang akan dilakukan ?
- Karakterisasi yang dilakukan untuk mendapatkan data mekanis dari material komposit ?
- Bagaimanakah performasi dari bahan serat komposit ini ?

- Adakah pengaruh terhadap material komposit akibat adanya perbedaan panjang serat ?

1.3 Pembatasan Masalah

Agar masalah tidak melebar dari pembahasan utama, maka permasalahan hanya dibatasi pada :

- Jenis komposit berserat alam berupa jerami dengan variasi panjang serat 20 mm dan 30 mm.
- Material pengikat adalah Resin epoksi.
- Pembuatan material komposit yang memiliki panjang serat 20 mm dan 30 mm dengan menggunakan *vacuum bag*.
- Pembuatan material komposit berserat jerami yang disusun acak dengan fraksi volume awal jerami 50 %.
- Teknik karakterisasi dengan melakukan pengujian mekanik berupa pengujian tarik (Standard ASTM D 638) dan pengujian bending (Standard ASTM D 790), serta dilakukan pengambilan foto pada hasil patahan dari spesimen pengujian mekanik.

1.4 Tujuan Penelitian

Tujuan dari dilakukan penelitian ini adalah :

- Mengetahui cara pembuatan material komposit dengan menggunakan *vacuum bag*.
- Mengetahui pengaruh panjang serat terhadap material komposit serat jerami.

- Mengetahui data pengujian mekanik, terutama pada kekuatan tarik dan bending yang paling optimal dari komposit serat jerami dengan matrik resin epoksi dan menganalisa struktur ikatan antara serat dan matrik.

1.5 Metode Penelitian

Langkah-langkah dalam melakukan penelitian ini adalah :

1. Tahap studi litelatur
   Mempelajari buku dan sumber-sumber referensi lain yang berkaitan dengan komposit untuk digunakan sebagai kajian dalam penelitian dan pengujian yang akan dilakukan.
2. Tahap penyiapan dan pembuatan
   Mempersiapkan alat-alat yang digunakan, pembuatan cetakan dan proses pembuatan komposit sampai menjadi spesimen pengujian mekanik.
3. Tahap pengujian
   Proses pengujian dengan mengacu pada litelatur yang sudah ada dan disesuaikan dengan standar pengujian dalam penelitian.
4. Tahap pengumpulan data dan analisis
   Pada tahap ini dilakukan pengumpulan data-data yang diperoleh dari hasil penelitian yang kemudian dianalisa, dan setelah itu diambil kesimpulan.

1.6 Sistematika Penulisan

Laporan penulisan Tugas Akhir ini disusun dengan sistematika sebagai berikut :

BAB I PENDAHULUAN

Berisi tentang latar belakang, perumusan masalah, pembatasan masalah, tujuan penelitian, metode penelitian dan sistematika penulisan laporan.

BAB II LANDASAN TEORI

Bab ini berisi tentang dasar teori mengenai material komposit, serat, matrik, proses *vacuum bag* dan pengujian mekanik.

BAB III PEMBUATAN KOMPOSIT DAN PENGUJIAN

Bab ini berisi tentang pembuatan komposit, penyiapan spesiman uji dan pengujian mekanis komposit dan diagram alir penelitian.

BAB IV HASIL DAN PEMBAHASAN

Bab ini berisi tentang perhitungan, pembahasan hasil perhitungan dan hasil pengujian pada material komposit.

BAB V KESIMPULAN DAN SARAN

Bab ini berisi tentang kesimpulan dan saran.

DAFTAR PUSTAKA

LAMPIRAN

BAB II
LANDASAN TEORI

2.1 Pengertian Material komposit

Kata komposit berasal dari kata kerja *"to compose"* yang berarti menyusun atau menggabung. Didalam dunia industri kata komposit dalam pengertian material komposit berarti terdiri dari dua atau lebih bahan yang berbeda yang digabung atau dicampur menjadi satu. Jadi secara sederhana material komposit berarti bahan gabungan dari dua atau lebih bahan yang berlainan.

Material komposit pada umumnya terdiri dari dua unsur, yaitu material pengisi (*filler*) dan material pengikat yang disebut matrik. Didalam komposit unsur utamanya adalah material pengisi sedangkan material pengikatnya menggunakan suatu material yang mudah dibentuk dan mempunyai daya pengikat yang tinggi. Fungsi dari material pengisi yaitu untuk menahan sebagian besar gaya yang bekerja pada material komposit, matrik sendiri mempunyai fungsi melindungi dan mengikat serat agar dapat bekerja dengan baik terhadap gaya-gaya yang terjadi.

Salah satu keunggulan dari material komposit bila dibandingkan dengan material lainnya adalah penggabungan unsur-unsur yang unggul dari masing masing unsur pembentuknya tersebut. Sehingga hasil penggabungan ini diharapkan dapat saling melengkapi kelemahan-kelemahan yang

ada pada masing-masing material penyusunnya. Sifat-sifat yang mungkin dapat diperbaharui contohnya, kekuatan, kekakuan, ketahanan korosi, ketahanan gesek, densitas, ketahanan lelah, konduktifitas panas dan lain-lain. Secara alami kemampuan tersebut diatas tidak ada semua pada waktu yang bersamaan (Jones, 1975).

Secara prinsip, komposit dapat tersusun dari berbagai kombinasi dua atau lebih material, baik material logam, material organik, maupun material non organik. Namun demikian bentuk dari unsur-unsur pokok material komposit adalah *fibers, particles, leminae, flakes* dan *matrix*. Secara garis besar komposit diklasifikasikan menjadi tiga macam yaitu, material komposit serat (*Fibers Composites*), material komposit partikel (*Particulate Composites*) dan material komposit lapis (*Laminates Composites*). Dalam penelitian ini jenis komposit yang dibuat yaitu material komposit serat.

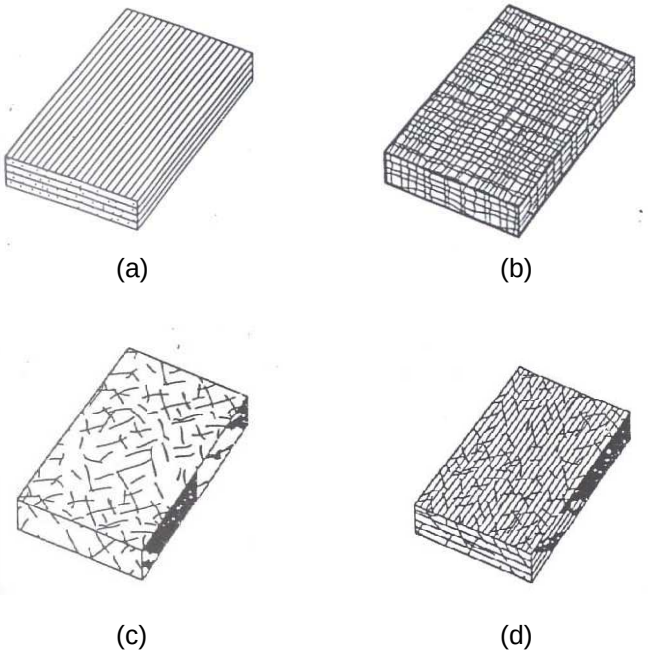
2.2 Material Komposit Serat

Komposit serat dalam dunia industri mulai dikembangkan dari pada mengunakan partikel. Dalam perkembangan teknologi pengolahan penggunaan serat sekarang makin diunggulkan dibandingkan material matrik yang digunakan. Serat yang digunakan bisa berupa *fibers glass*, *carbon fibers*, *aramid fibers* (*poly aramide*), *natural fibers* dan sebagainya.

Material komposit serat tersusun atas serat-serat yang diikat oleh matrik yang saling berhubungan. Pengunaan material

komposit serat sangat efisien dalam menerima beban dan gaya yang searah serat, sebaliknya sangat lemah bila dibebani dalam arah tegak lurus serat (Hadi, 2000).

Untuk mendapatkan suatu material komposit yang kuat penempatan serat sangat berpengaruh. Oleh karena itu ada beberapa tipe penempatan serat untuk membuat material komposit serat yang baik.



Gambar 2.1. Tipe komposit serat : (a) *Continuous Fiber Composite* , (b) *Woven Fiber Composite*, (c) *Randomly oriented discontinuous fiber*, (d)*Hybrid fiber composite.*

Berdasarkan penempatannya terdapat beberapa tipe serat pada komposit, yaitu :

1) *Continuous Fiber Composite*

   Continuous atau uni-directional, mempunyai susunan serat panjang dan lurus, membentuk lamina diantara matriknya. Jenis komposit ini paling sering digunakan. Tipe ini mempunyai kelemahan pada pemisahan antar lapisan. Hal ini dikarenakan kekuatan antar lapisan dipengaruhi oleh matriknya.

2) *Woven Fiber Composite (bi-dirtectional)*

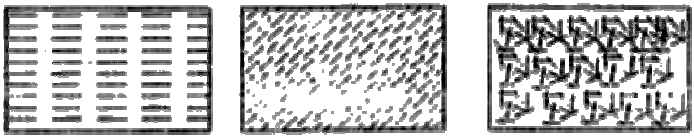
   Komposit ini tidak mudah dipengaruhi pemisahan antar lapisan karena susunan seratnya juga mengikat antar lapisan. Akan tetapi susunan serat memanjangnya yang tidak begitu lurus mengakibatkan kekuatan dan kekakuan akan melemah.

3) *Discontinuous Fiber Composit*

   Discontinuous Fiber Composite adalah tipe serat pendek. Tipe ini dibedakan jadi tiga :

   a) *Aligned discontinuous fiber*
   b) *Off-axis aligned discontinuous fiber*
   c) *Randomly oriented discontinuous fiber*

   Tipe acak sering digunakan pada produksi dengan volume besar karena faktor biaya manufakturnya yang lebih murah. Kekurangan dari jenis serat acak adalah sifat mekanik yang dibawah dari penguatan dengan serat lurus pada jenis serat yang sama.



(a) *aligned* (b) *off-axis* (c) *randomly*

Gambar 2.2. Tipe *discontinuous fiber*

4) *Hybrid Fiber Composite*

Hybrid fiber composite merupakan komposit gabungan antara tipe serat lurus dengan serat acak. Tipe ini digunakan supaya dapat menganti kekurangan sifat dari kedua tipe dan dapat menggabungkan kelebihannya.

2.3 Faktor Yang Mempengaruhi Komposit Serat

Penelitian yang mengabungkan antara matrik dan serat harus memperhatikan beberapa faktor. Faktor yang mempengaruhi performa material komposit serat antara lain :

a) Faktor Serat

Serat adalah material pengisi matrik yang digunakan untuk dapat memperbaiki sifat dan struktur matrik yang tidak dimilikinya, juga diharapkan mampu menjadi material penguat matrik pada komposit untuk menahan gaya yang terjadi.

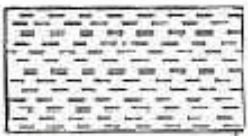
b) Letak Serat

Dalam pembuatan komposit tata letak dan arah serat dalam matrik yang akan menentukan kekuatan mekanik

komposit, dimana letak dan arah dapat mempengaruhi kinerja komposit tersebut. Menurut tata letak dan arah serat diklasifikasikan menjadi tiga bagian yaitu :

- *One dimensional reinforcement*, mempunyai kekuatan dan modulus maksimum pada arah axis serat.
- *Two dimensional reinforcement* (planar), mempunyai kekuatan pada dua arah atau masing-masing arah orientasi serat.
- *Three dimensional reinforcement*, mempunyai sifat *isotropic* kekuatannya lebih tinggi dibanding dengan dua tipe sebelumnya.

Pada pencapuran dan arah serat mempunyai beberapa keunggulan, jika orientasi serat semakin acak (random) maka sifat mekanik pada 1 arahnya akan melemah, bila arah tiap serat menyebar maka kekuatannya juga akan menyebar kesegala arah maka kekuatan akan meningkat.



One dimensional reinforcement

Two dimensional reinforcement

Three dimensional reinforcement

Gambar 2.3. Tiga tipe orientasi pada *reinforcement*

c) Panjang Serat

Panjang serat dalam pembuatan komposit serat pada matrik sangat berpengaruh terhadap kekuatan. Ada dua penggunaan serat dalam campuran komposit yaitu serat pendek dan serat panjang. Serat panjang lebih kuat dibanding serat pendek. Serat alam jika dibandingkan dengan serat sintetis mempunyai panjang dan diameter yang tidak seragam pada setiap jenisnya. Oleh karena itu panjang dan diameter sangat berpengaruh pada kekuatan maupun modulus komposit. Serat panjang (*continous fiber*) lebih efisien dalam peletakannya daripada serat pendek (dis*continous fiber*). Akan tetapi, serat pendek lebih mudah peletakannya dibanding serat panjang. Panjang serat mempengaruhi kemampuan proses dari komposit serat.

Ditinjau dari teorinya, serat panjang dapat mengalirkan beban maupun tegangan dari titik tegangan ke arah serat yang lain. Pada struktur *continous fiber* yang ideal, serat akan bebas tegangan atau mempunyai tegangan yang sama. Selama fabrikasi, beberapa serat akan menerima tegangan yang tinggi dan yang lain mungkin tidak terkena tegangan sehingga keadaan di atas tidak dapat tercapai. Sedangkan komposit serat pendek, dengan orientasi yang benar, akan menghasilkan kekuatan yang lebih besar jika dibandingkan *continous fiber*. Komposit berserat pendek dapat diproduksi dengan cacat permukaan yang rendah sehingga kekuatannya dapat mencapai kekuatan teoritisnya.

d) Bentuk Serat

Bentuk Serat yang digunakan untuk pembuatan komposit tidak begitu mempengaruhi, yang mempengaruhi adalah diameter seratnya. Pada umumnya, semakin kecil diameter serat akan menghasilkan kekuatan komposit yang lebih tinggi. Selain bentuknya kandungan seratnya juga mempengaruhi (Schwartz, 1984).

e) Faktor Matrik

Matrik dalam komposit berfungsi sebagai bahan pengikat serat menjadi sebuah unit struktur, melindungi dari perusakan eksternal, meneruskan atau memindahkan beban eksternal pada bidang geser antara serat dan matrik, sehingga matrik dan serat saling berhubungan. Pembuatan komposit serat membutuhkan ikatan permukaan yang kuat antara serat dan matrik. Selain itu matrik juga harus mempunyai kecocokan secara kimia agar reaksi yang tidak diinginkan tidak terjadi pada permukaan kontak antara keduanya. Untuk memilih matrik harus diperhatikan sifat-sifatnya, antara lain seperti tahan terhadap panas, tahan cuaca yang buruk dan tahan terhadap goncangan yang biasanya menjadi pertimbangan dalam pemilihan material matrik. Material Polimer yang sering digunakan sebagai material matrik dalam komposit ada dua macam yaitu *thermoplastik* dan *termoset*.

f) Fraksi Volume Antara Material Pengisi dan Matrik

Jumlah kandungan serat dalam komposit, merupakan hal yang menjadi perhatian khusus pada komposit berpenguat

serat. Untuk memperoleh komposit berkekuatan tinggi, distribusi serat dengan matrik harus merata pada proses pencampuran agar mengurangi timbulnya *void*. Untuk menghitung fraksi volume, parameter yang harus diketahui adalah berat jenis resin, berat jenis serat, berat komposit dan berat serat. Jika selama pembuatan komposit diketahui massa serat dan matrik, serta densitas serat dan matrik, maka fraksi volume dan fraksi massa serat dapat dihitung dengan persamaan (Shackelford, 1992) :

$$V_f = \frac{W_f \,/\, \rho_f}{W_f \,/\, \rho_f + W_m \,/\, \rho_m} \quad \text{..... [2.1]}$$

Keterangan :

V_f = Fraksi volume serat

W_f = Berat serat

W_m = Berat matrik

ρ_f = Massa jenis serat

ρ_m = Massa jenis matrik

2.4 Serat Jerami

Penggunaan serat pada komposit bertujuan untuk dapat memperbaiki sifat dan struktur matrik yang tidak dimilikinya, juga diharapkan mampu menjadi bahan penguat matrik pada komposit untuk menahan gaya yang terjadi. Serat sudah terkenal sejak dahulu karena struktur yang kuat terutama kekuatan tariknya.

Selain itu serat juga merupakan unsur yang terpenting, karena seratlah nantinya yang akan menentukan sifat mekanik komposit tersebut seperti kekakuan, keuletan, kekuatan dan sebagainya.

Serat mempunyai bentuk tipis dan panjang, dan mempunyai ciri-ciri cukup pada struktur dalamnya. Serat berdasarkan unsur pembentuknya ada dua, pertama adalah serat alam (*natural fibers*), yaitu serat yang berasal dari hewan, tumbuhan dan mineral, contonya kapas, wol, sutra, rami dan serat alam lainnya. Kedua serat sintetik (*synthetic fibers*) yaitu serat buatan seperti nilon, rayon, acetates poliester dan lain-lain. Pada penelitian ini menggunakan serat alam yaitu serat jerami.

Jerami adalah bagian batang tumbuh yang telah dipanen bulir-bulir buah(beras) bersama atau tidak dengan tangkainya dikurangi dengan akar dan bagian batang yang tertinggal. Pada saat ini pemanfaatan jerami kurang efisien, biasanya hanya untuk kebutuhan ternak dan untuk keperluan berkebun sebagai pupuk bahkan justru akhirnya hanya dibakar hingga menimbulkan polusi. Sehingga banyak limbah jerami dari hasil tani padi.

Kini, dengan penelitian lebih lanjut, jerami ternyata juga bisa dimanfaatkan sebagai material pengisi pada material komposit. Dengan ketersedian yang sangat banyak tersebut maka jerami bisa dimanfaatkan sebagai serat komposit yang murah dan ramah lingkungan.

	Elemental Analysis					Predicted Substance Density (kg/m^3)
	C	H	O	Si	Other	
Elementari Density (kg/m^3)	1950*	1000	1000	2320	2000**	
	Density(% by weight, dry basis)					
Type of Material						
Softwood	50	6	43	0	1	1485
Rice Straw	42	5	37	12	4	1597
Rice Hulls	41	4	36	15	4	1628

Tabel 2.1. *Substance density for softwood, rice straw and rice hulls based on elemental density analysis* (Matthew, 2000).

2.5 Matrik Resin Epoksi

Dalam pembuatan sebuah komposit, matrik berfungsi sebagai pengikat material pengisi/penguat, dan juga sebagai pelindung partikel dari kerusakan oleh faktor lingkungan. Beberapa bahan matriks dapat memberikan sifat-sifat yang diperlukan seperti keliatan dan ketangguhan.

Matrik yang digunakan dalam komposit adalah harus mampu meneruskan beban sehingga serat harus bisa melekat pada matrik dan kompatibel antara serat dan matrik artinya tidak ada reaksi yang mengganggu. Pada penelitian ini matrik yang digunakan adalah *resin termoset* dengan jenis resin epoksi.

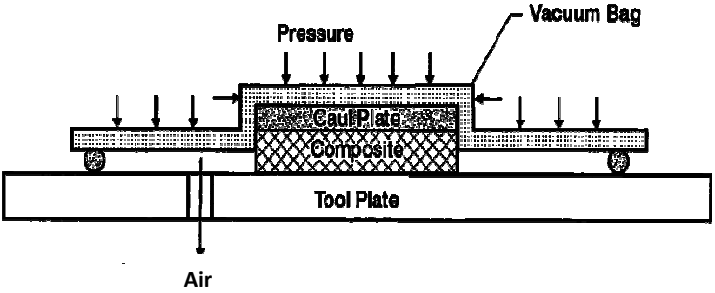
Sifat-sifat	Satuan	Nilai Tipikal	Keterangan
Massa jenis	g/cm^3	1,17	
Penyerapan air	^0c	0,2	
Kekuatan tarik	Kgf/mm^2	5,95	
Kekuatan tekan	Kgf/mm^2	14	
Kekuatan lentur	Kgf/mm^2	12	
Temperatur pencetakan	^0c	90	

Tabel 2.2. Spesifikasi resin epoksi (Surdia, 1985).

Resin epoksi mempunyai kegunaan yang luas dalam industri kimia teknik, listrik, mekanik, dan sipil sebagai bahan perekat, cat pelapis, dan benda-benda cetakan. Selain itu resin epoksi juga mempunyai ketahanan kimia yang baik. Sifatnya bervariasi bergantung pada jenis, kondisi dan pencampuran dengan pengerasnya.

2.6 Vacuum Bag Moulding

Suatu proses pembuatan material komposit bermacam-macam, salah satunya *vacuum bag moulding.* Metode ini adalah pengembangan dari metode *hand lay up.*



Gambar 2.4. *Vacuum Bag Moulding*

Dengan metode *vacuum bag moulding* cetakan berisi komposit akan dimasukan kedalam kantong kedap udara kemudian udara didalam kantong tersebut akan dipompa keluar. Fungsinya yaitu untuk menghilangkan *void-void* atau rongga dengan memaksa keluar udara yang terperangkap. Cara ini termasuk cara yang ekonomis dan mudah dilakukan.

2.7 Pengujian Tarik

Pengujian tarik dilakukan untuk mencari tegangan dan regangan (*stress strain test*). Dari pengujian ini dapat kita ketahui beberapa sifat mekanik material yang sangat dibutuhkan dalam desain rekayasa. Hubungan antara tegangan dan regangan pada beban tarik ditentukan dengan rumus sebagai berikut :

Tegangan teknik :

$$\sigma = \frac{F}{A_0} \quad \text{..... [2.2]}$$

Regangan teknik :

$$\varepsilon = \frac{l_1 - l_0}{l_0} = \frac{\Delta L}{l_0} \quad \text{..... [2.3]}$$

Besarnya nilai modulus elastisitas benda yang juga merupakan perbandingan antara tegangan dan regangan pada daerah proporsional dapat dihitung dengan persamaan (Surdia, 1995) :

$$E = \frac{\sigma}{\varepsilon} \quad \text{.....[2.4]}$$

Keterangan :

σ = Tegangan (MPa)

F = Beban (N)

A_0 = Luas penampang (mm^2)

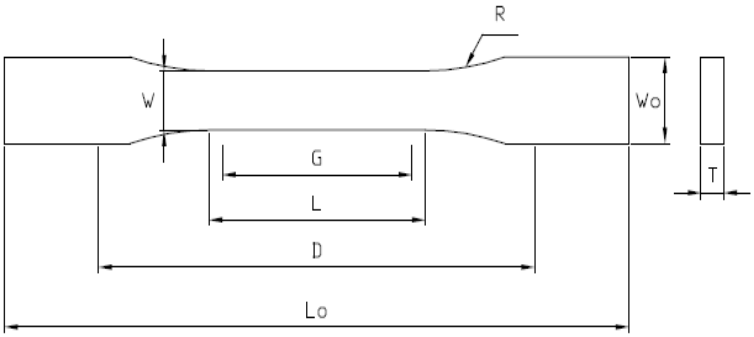
ε = Regangan

E = Modulus elastisitas tarik (MPa)

l_0 = Panjang daerah ukur (mm)

ΔL = Pertambahan panjang (mm)

Pengujian yang dilakukan untuk matrik (jenis plastik resin) dan kompositnya, dapat menggunakan standar pengujian ASTM D 638.



Gambar 2.5. *Neat resin tensile specimen for thicknesses of* 0.28 in (7 mm) *or less*. (*From ASTM Standard* D 638)

Keterangan :

W = *Width of narrow section* 13 mm

L = *Length of narrow section* 57 mm

W_o = *Width overall*, min. 19 mm

L_o = *Length overall*, min. 165 mm

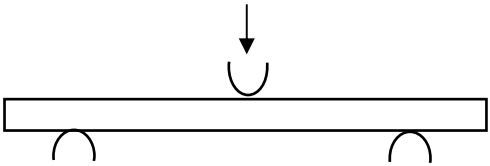
G = *Gage lenght* 50 mm

D = *Distance between grips* 115 mm

R = *Radius of fillet* 76 mm

2.8 Pengujian Bending

Untuk mengetahui kekuatan bending suatu material dapat dilakukan dengan pengujian bending terhadap material tersebut. Kekuatan bending atau kekuatan lengkung adalah tegangan bending terbesar yang dapat diterima akibat pembebanan luar tanpa mengalami deformasi yang besar atau kegagalan. Pengujian bending yang dilakukan untuk matrik (jenis plastik resin) dan komposit terdiri dari dua macam, yang pertama disebut *three point bending* dan yang kedua disebut *four point bending*. Yang digunakan dalam penelitian ini adalah *three point bending.*



Gambar 2.6. *Three point bending.* (*From ASTM Standard* D 790)

Akibat Pengujian bending, bagian atas spesimen mengalami tekanan, sedangkan bagian bawah akan mengalami tegangan tarik. Dalam material komposit kekuatan tekannya lebih tinggi dari pada kekuatan tariknya. Karena tidak mampu menahan tegangan tarik yang diterima, spesimen tersebut akan patah, hal tersebut mengakibatkan kegagalan pada pengujian komposit. Kekuatan bending pada sisi bagian atas sama nilai dengan kekuatan bending pada sisi bagian bawah.

Untuk mencari tegangan bending dan modulus elastisitas bending yaitu dengan menggunakan persamaan sebagai berikut :

Tegangan bending :

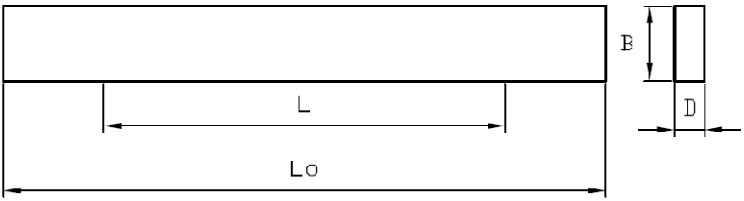
$$\sigma_b = \frac{3PL}{2bd^2} \quad \text{..... [2.5]}$$

Modulus elastisitas bending :

$$E_b = \frac{L^3 P}{4bd^3\delta} \quad \text{..... [2.6]}$$

Keterangan :

σ_b = Tegangan bending (MPa)
P = Beban (N)
E_b = Modulus elastisitas bending (MPa)
δ = Defleksi (N/mm)
L = Panjang Span/jarak antara titik tumpuan, 80 mm
L_o = Panjang spesimen, 120 mm
b = Lebar spesimen, 15 mm
d = Tebal spesimen, 6 mm



Gambar 2.7. Bentuk spesimen uji bending standar ASTM D790.

BAB III
PEMBUATAN KOMPOSIT JERAMI-EPOKSI DAN PENGUJIAN

3.1 Persiapan Alat dan Bahan

3.1.1 Alat

a. *Vakuum Bag*

Penggunaan *vacuum bag* dimaksudkan untuk mengurangi kemungkinan terjadinya *void-void* pada komposit.

Gambar 3.1. *Vacuum bag* dan *Mini pump.*

b. Timbangan Digital

Digunakan untuk menimbang serat dan resin eposi.

Gambar 3.2. Timbangan digital.

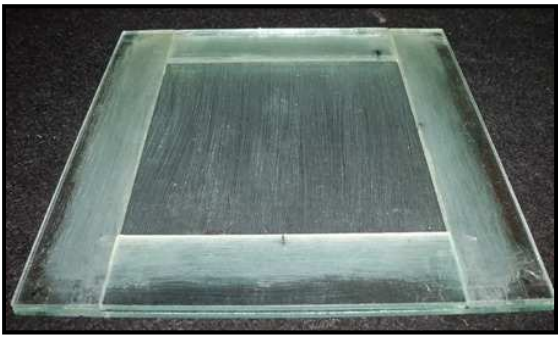
c. Gelas Ukur

Digunakan untuk pengujian densitas serat dan juga sebagai takaran resin epoksi pada saat pembuatan komposit.

Gambar 3.3. Gelas Ukur.

d. Cetakan

Cetakan terbuat dari kaca dengan dimensi keseluruhan yaitu panjang 30 mm, lebar 30 mm dan tebal 16 mm. Dimensi untuk ruang cetak komposit yaitu panjang 20 mm, lebar 20 mm dan tebal 6 mm.



Gambar 3.4. Cetakan.

e. Klem

Digunakan sebagai alat untuk pengepres/penekan cetakan pada saat pembuatan material komposit.

Gambar 3.5. Klem.

f. Mesin Gergaji

Berfungsi sebagai alat pemotong material komposit untuk membuat spesimen pengujian tarik dan pengujian bending.

Gambar 3.6. Mesin gergaji.

g. Alat Bantu Lain

Terdiri dari *Pressure Gauge Vacuum,* sendok, *cutter*, gunting, kuas, pisau, spidol, pulpen, solatip, klip, busa dan penggaris.

Gambar 3.7. Alat-alat bantu lainnya.

3.1.2 Bahan

a. Serat Jerami

Digunakan sebagai penguat pada material komposit. Ukuran serat antara lain 20 mm dan 30 mm.

Gambar 3.8. Serat jerami mulai dari kiri 20 mm dan kanan 30 mm.

b. Resin Epoksi

Digunakan sebagai pengikat serat pada material komposit. Resin epoksi dengan merek Indomol diproduksi oleh Dian Utama Putra terdiri dari resin dan hardener.

Gambar 3.9. Resin Epoksi dan Hardener.

c. Larutan NaOH

Larutan basa yang digunakan untuk membersihkan kotoran pada serat jerami.

Gambar 3.10. Larutan NaOH.

d. Maximum Mold Release Wax

Wax berfungsi sebagai pelapis cetakan agar material komposit yang sudah jadi akan mudah untuk dilepaskan dari cetakan.

Gambar 3.11. *Wax*.

3.2 Proses Pembuatan Komposit

Berikut ini adalah langkah-langkah proses pembuatan material komposit sampai menjadi spesimen pengujian tarik dan bending.

a. Siapkan serat jerami yang telah dipotong sesuai ukuran 20 mm dan 30 mm.
b. Cuci lalu rendam masing-masing serat jerami pada larutan NaOH selama satu jam dengan wadah yang berbeda agar ukuran serta satu tidak tercampur dengan ukuran serat lainnya, setelah satu jam cuci kembali lalu keringkan.
c. Siapkan cetakan lalu lapisi ruang cetaknya dengan *wax*, gunakan kuas untuk mengoleskan *wax* secara merata.

d. Timbanglah serat jerami dan campuran resin epoksi sesuai dengan fraksi volume yang telah dihitung. Campuran antara epoksi dan hardener yaitu 1:1.
e. Tuangkan setengah dari campuran resin epoksi kedalam cetakan, tempatkan serat jerami pada cetakan yang sebelumnya telah di isi dengan resin epoksi lalu tekan-tekan dan ratakan dengan menggunakan sendok supaya memenuhi ruang cetak, selanjutnya tuangkan sisa campuran resin epoksi pada cetakan dan tekan-tekan kembali agar campuran resin epoksi tersebut masuk diantara serat-seratnya, setelah itu tutup dengan kaca.
f. Pasang klem pada cetakan yang telah di isi tersebut supaya terjadi pengepresan/penekanan secara merata sehingga memadatkan campuran antara resin epoksi dan serat jerami.
g. Setelah proses ini pasangkan klip-klip pada seluruh sisi cetakan, masing-masing sisi terdiri dari 3 klip. Klip ini berfungsi sebagai pengganti klem karna klem akan dilepas sebelum cetakan dimasukan kedalam *vacuum bag*.
h. Lapisi/bungkus sisi-sisi cetakan yang berisi material komposit berserat jerami 20 mm dan 30 mm dengan menggunakan busa. Busa berfungsi untuk mencegah terjadinya sobekan pada plastik vakum oleh klip dan sisi-sisi cetakan kaca yang tajam.
i. Masukan cetakan yang telah dilapisi dengan busa-busa tersebut kedalam *vacuum bag* (cetakan berisi material komposit berserat jerami 20 mm dan 30 mm), tutup rapat-

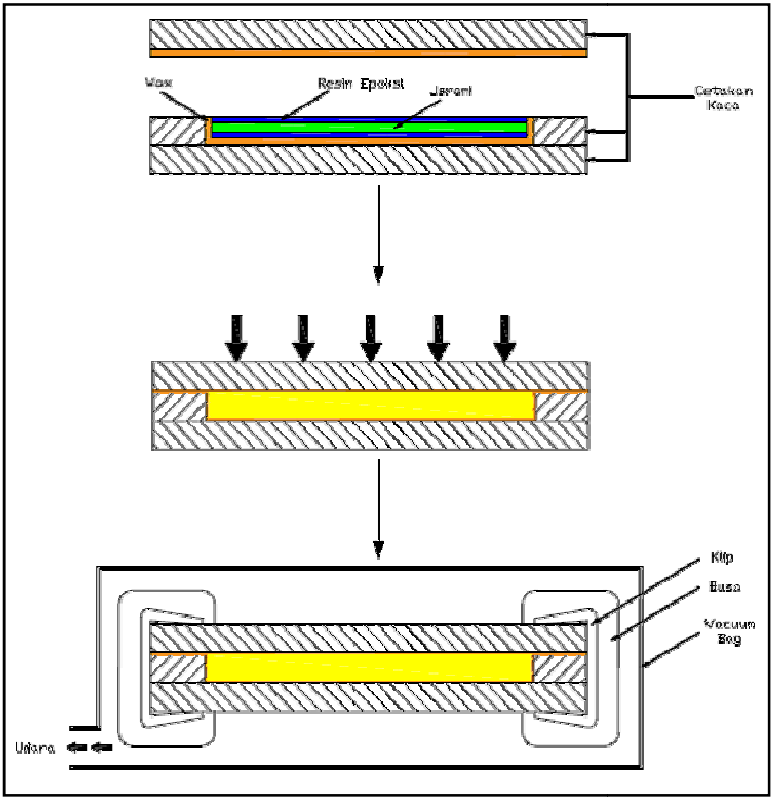
rapat *vacuum bag* lalu sedot udara didalamnya dengan menggunakan *mini pump* sampai panah pada *vacuum pressure gauge* menunjuk ke nilai antara -0,02 sampai -0.1 cmHg.

j. Keringkan, lama proses pengeringan antara 12 – 15 jam.

k. Setelah benar-benar kering ambil cetakan dan lepas klem atau klip lalu bongkar cetakan tersebut dengan menggunakan pisau atau *cutter*.

l. Bersihkan material komposit yang sudah jadi dari sisa-sisa *wax* dan tempelkan pola yang berbentuk spesimen pengujian tarik dan bending pada permukaan material komposit tersebut. Pola berfungsi sebagai jalur penggergajian pembuatan spesimen pengujian tarik dan bending.

m. Potong material komposit mengikuti jalur pola yang telah dibuat dengan menggunakan mesin gergaji.



Gambar 3.12. Skematik pembuatan material komposit.

Gambar 3.13. Material komposit jerami epoksi.

Gambar 3.14. Spesimen pengujian tarik.

Gambar 3.15. Spesimen pengujian bending.

3.3 Pengujian Mekanik

Pengujian mekanik berupa pengujian tarik dan pengujian bending dilaksanakan di Politeknik Bandung dengan menggunakan mesin buatan jepang merk Tokyo Koki Seizosho kapasitas 10 ton tahun produksi 1981.

Gambar 3.16. Mesin pengujian tarik dan bending.

3.3.1 Pengujian Tarik

Spesimen pengujian tarik menggunakan standard ASTM D 638. Jumlah spesimen yang di uji yaitu 6 dengan rincian :

- 3 spesimen komposit berserat jerami 20 mm.
- 3 spesimen komposit berserat jerami 30 mm.

Gambar 3.17. Komponen pengujian tarik.

Langkah-langkah pengujian tarik dalam penelitian ini adalah sebagai berikut :

a. Siapkan spesimen pengujian tarik dan lakukan pengukuran sebagai data awal spesimen.
b. Siapkan mesin pengujian tarik.
c. Pasang spesimen pengujian pertama jepit pada chuck atas kemudian atur chuck bawah untuk menjepit spesimen dengan tepat. Pastiakn kedua chuck menjepit dengan kuat.
d. Jalankan mesin dengan kecepatan penarikan konstan.
e. Karna alat plotter grafik pada mesin tidak berfungsi, maka lakukan pembacaan secara manual dengan cara mencatat perubahan beban yang terjadi pada setiap pertambahan panjang 0,1 mm (Data yang didapatkan bisa dibuat grafik).
f. Setelah spesimen patah hentikan proses penarikan dengan cara mematikan motor secara perlahan.

3.3.2 Pengujian Bending

Spesimen pengujian bending menggunakan standard ASTM D 790. Jumlah spesimen yang di uji yaitu 6 dengan rincian :

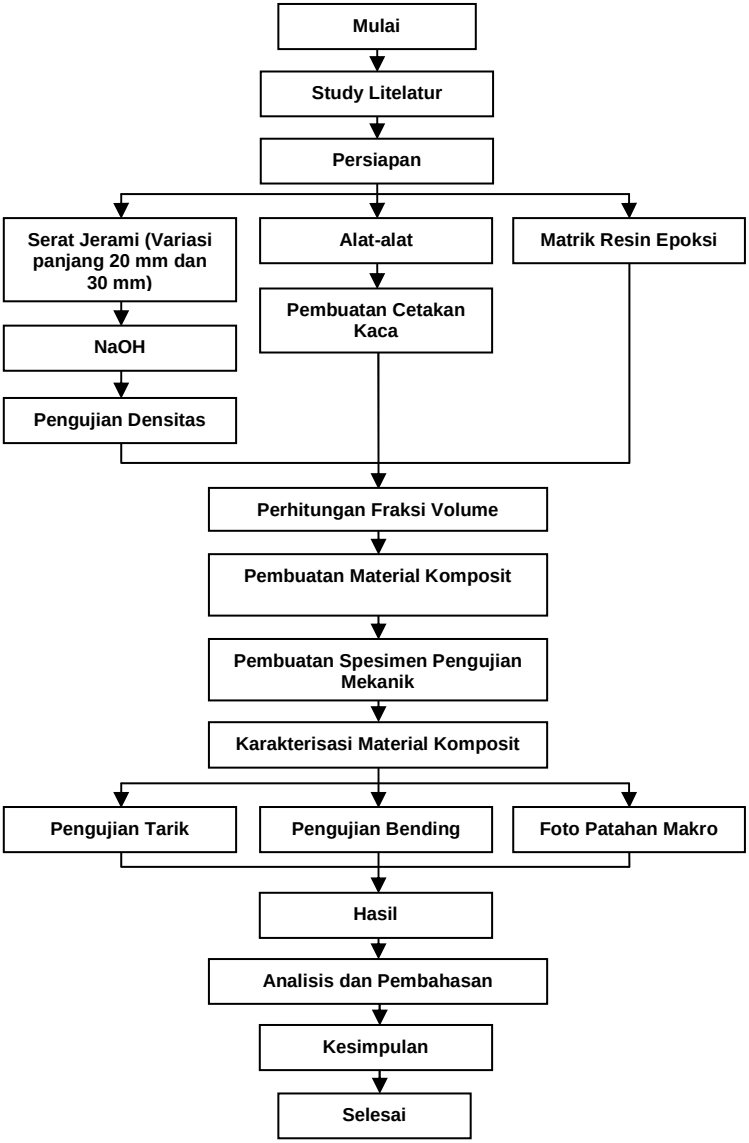
- 3 spesimen pengujian bending komposit berserat jerami 20 mm.
- 3 spesimen pengujian bending komposit berserat jerami 30 mm.

Gambar 3.18. Komponen pengujian bending.

Langkah-langkah pengujian bending dalam penelitian ini adalah sebagai berikut :

a. Siapkan spesimen pengujian bending, lakukan peng-ukuran sebagai data awal spesimen dan tentukan titik tumpuan serta titik tengah dengan memberi tanda garis.
b. Tempatkan spesimen pada komponen penumpu, pastikan tepat dengan garis tumpuan yang telah dibuat.
c. Atur indentor penekan sampai menyentuh spesimen.
d. Jalankan mesin dengan kecepatan penekanan konstan.
e. Catat perubahan beban yang terjadi pada setiap defleksi 0,1 mm sampai spesimen patah.
f. Matikan mesin secara parlahan setelah spesimen patah

3.4 Diagram Alir Penelitian



Gambar 3.19. Diagram alir penelitian.

BAB IV
HASIL DAN PEMBAHASAN

4.1 Analisis Fraksi Volume Akhir

Setelah material komposit jadi dilakukan perhitungan fraksi volume akhir, ini dilakukan untuk mendapatkan harga fraksi volume sebenarnya. Fraksi volume akhir di tentukan dengan membandingkan berat komposit pada timbangan dengan berat komposit hasil perhitungan. Perhitungan bisa dilakukan dengan mengolah persamaan densitas.

$\rho = \frac{m}{v}$ => $\rho \times v = m$

$m_{resin} + m_{serat} = m_{composit}$ maka,

$(\rho_r \times v_r) + (\rho_s \times v_s) = m_c$

Dengan menskalakan volume serat dan volume resin dari 1-100 maka akan didapatkan berat komposit dari 1% sampai dengan 100%, setelah didapatkan akan dibandingkan dengan berat hasil penimbangan. Berat yang diambil sebagai patokan fraksi volume adalah berat komposit hasil perhitungan yang paling mendekati berat hasil penimbangan.

Dari data hasil perhitungan maka pada material komposit serat 20 mm dengan data awal volume komposit 2,001 cm^3 yang

paling mendekati dengan berat hasil penimbangan 1,95 gr adalah pada fraksi volume 35% yaitu 1,97 gr.

Pada material komposit serat 30 mm dengan data awal volume komposit 2,0445 cm^3 yang paling mendekati dengan berat hasil penimbangan 2 gr adalah pada fraksi volume 35% yaitu 2,014 gr.

4.2 Hasil Pengujiaan Tarik

Dari data-data hasil pengujian tarik pada material komposit jerami epoksi maka bisa dihitung antara lain, tegangan tarik, regangan tarik dan modulus elastisitas tarik.

Spesimen pengujian tarik	Panjang serat jerami	
	20 mm	30 mm
I (MPa)	18,45	18,15
II (MPa)	17,88	23,05
III (MPa)	20,66	17,83
Rata-rata (MPa)	18,99	19,68

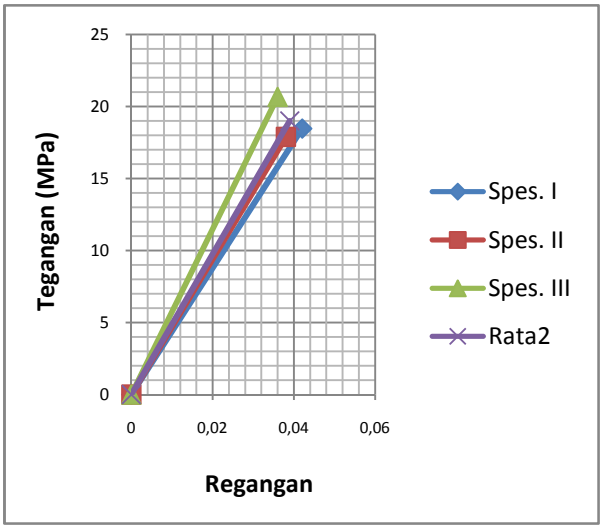
Tabel 4.1. Kekuatan tarik (σ) material komposit.

Tegangan tarik rata-rata pada material komposit jerami epoksi untuk panjang serat jerami 20 mm mencapai harga 18,99 MPa, sedangkan untuk panjang serat 30 mm adalah 19,67 MPa.

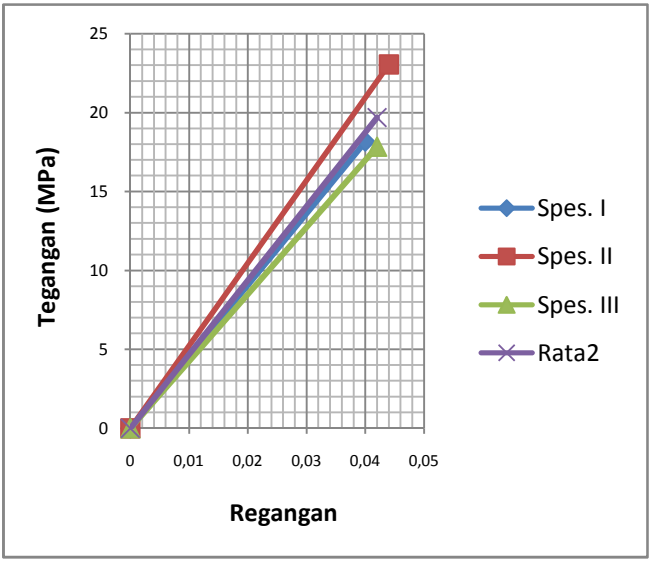
Spesimen pengujian tarik	Panjang serat jerami (mm)	
	20 mm	30 mm
I	0,042	0,04
II	0,038	0,044
III	0,036	0,042
Rata-rata	0,039	0,042

Tabel 4.2. Elongasi (ε) material komposit.

Harga regangan tarik rata-rata pada material komposit jerami epoksi untuk panjang serat jerami 20 mm adalah 0,039, sedangkan untuk panjang serat 30 mm adalah 0,042.



Grafik 4.1. Grafik σ - ε pada material komposit serat 20 mm.



Grafik 4.2. Grafik σ - ε pada material komposit serat 30 mm.

Spesimen pengujian tarik	Panjang serat jerami	
	20 mm	30 mm
I (MPa)	439,28	453,79
II (MPa)	470,46	523,78
III (MPa)	573,98	424,58
Rata-rata (MPa)	494,57	467,38

Tabel 4.3. Modulus elastisitas (E) tarik material komposit.

Harga modulus elastisitas rata-rata pada material komposit jerami epoksi untuk panjang serat jerami 20 mm adalah 494,57 MPa, sedangkan untuk panjang serat 30 mm adalah 467,38 Mpa.

4.3 Hasil Pengujian Bending

Dari data-data hasil pengujian bending pada material komposit jerami epoksi maka bisa dihitung antara lain, tegangan bending dan modulus elastisitasmbending.

Spesimen pengujian bending	Panjang serat jerami	
	20 mm	30 mm
I (MPa)	103,87	98,4
II (MPa)	92,98	105,1
III (MPa)	97,31	93,09
Rata-rata (MPa)	98,05	98,86

Tabel 4.4. Kekuatan bending (σ_b) material komposit.

Tegangan bending rata-rata pada material komposit jerami epoksi untuk panjang serat jerami 20 mm mencapai harga 98,05 MPa, sedangkan untuk panjang serat 30 mm adalah 98,86 MPa.

Spesimen pengujian bending	Panjang serat jerami	
	20 mm	30 mm
I (MPa)	3687,34	2936,91
II (MPa)	3954,37	3556,94
III (MPa)	3941,75	3213,55
Rata-rata (MPa)	3861,15	3235,8

Tabel 4.5. Modulus elastisitas (E_b)bending material komposit.

Modulus elastisitas bending rata-rata pada material komposit jerami epoksi untuk panjang serat jerami 20 mm mencapai harga 3861,15 MPa, sedangkan untuk panjang serat 30 mm adalah 3235,8 MPa.

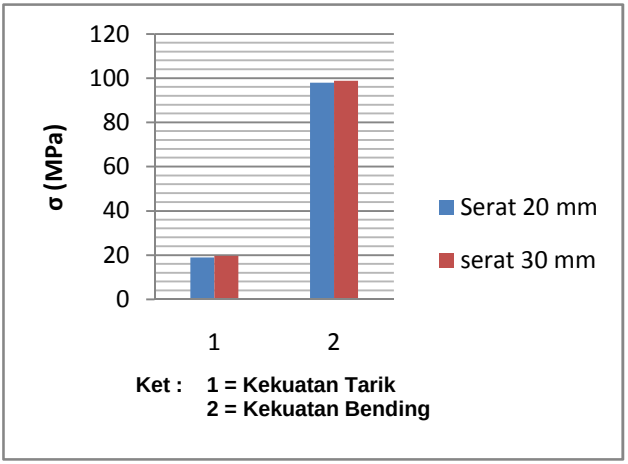
4.4 Pembahasan Hasil Perhitungan

Berikut dibawah ini adalah tabel pengolahan data yang menunjukan harga rata-rata dari tiap parameter yang dihitung.

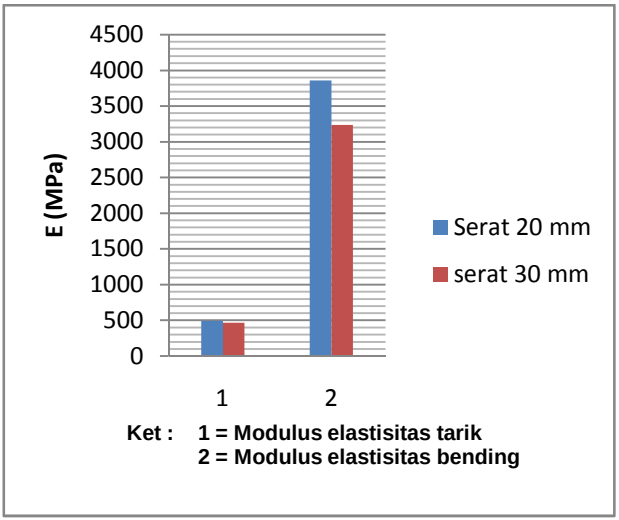
Material Kompost	Vf (%)	Harga rata-rata				
		σ_{max} (MPa)	ε	E (MPa)	$\sigma_{b\ max}$ (MPa)	E_b (MPa)
Serat 20 mm	35	18,99	0,039	494,57	98,1	3861
Serat 30 mm	35	19,68	0,042	467,38	98,9	3236

Tabel 4.6. Hasil Pengolahan Data.

Dari tabel diatas dapat dilihat, tegangan tarik paling tinggi adalah pada material komposit dengan panjang serat jerami 30 mm yaitu 19,68 MPa, regangan tarik paling tinggi adalah pada material komposit dengan panjang serat jerami 30 mm yaitu 0,042 dan modulus elastisitas tarik paling tinggi adalah pada material komposit dengan panjang serat jerami 20 mm yaitu 494,57 MPa, sedangkan pada pengujian bending harga rata-rata paling optimal dari setiap parameter yang terdiri dari, tegangan bending paling tinggi adalah pada material komposit dengan panjang serat jerami 30 mm yaitu 98,86 Mpa dan modulus elastisitas bending paling tinggi adalah pada material komposit dengan panjang serat jerami 20 mm yaitu 3861,15 MPa.



Grafik 4.3. Pengaruh panjang serat terhadap kekuatan dari material komposit.



Grafik 4.4. Pengaruh panjang serat terhadap modulus elastisitas material komposit.

Seperti menurut teori bahwa panjang serat mempengaruhi kekuatan komposit. Pada material komposit ini tegangan tarik dan tegangan bending paling optimal yaitu pada material komposit dengan panjang serat jerami 30 mm.

Dilihat dari sifat mekaniknya ternyata pada material komposit jerami-epoksi ini memiliki sifat tekan yang lebih baik dari sifat tarik, itu dapat diketahui dari harga kekuatan bending yang jauh lebih besar dari kekuatan tarik.

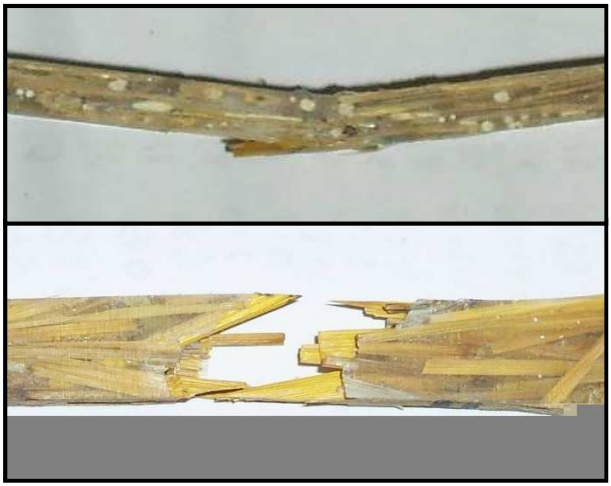
Material komposit ini bersifat kaku, kekakuatan yang paling besar adalah pada material komposit dengan serat 20 mm karna memiliki modulus elastisitas yang lebih besar dari serat 30 mm.

Pengujian pada material komposit belum tentu membawa hasil yang benar-benar baik itu bisa dilihat pada banyak faktor antara lain :

- Pada faktor serat, penempatan serat kurang seragam dan merata sehingga kemungkinan penurunan kekuatan bisa terjadi.
- Adanya *void-void* yang sudah jelas mengindikasikan material yang jelek, void ini terjadi karena pada proses pembuatan material komposit dilakukan kurang terlalu benar.
- Bentuk serat, khususnya diameter serat jerami yang terlalu besar. Dalam teori dikatakan, semakin kecil diameter serat akan menghasilkan kekuatan komposit yang lebih tinggi.

4.5 Struktur Ikatan Serat dan Matrik

Bagus tidaknya struktur ikatan antara serat dan matrik salah satunya bisa dilihat pada patahan hasil pengujian mekanik.



Gambar 4.1. Patahan hasil pengujian mekanik.

Dilihat dari foto diatas setelah patah ternyata ada sebagian serat yang tidak putus tetapi hanya lepas dari matrik. Itu menandakan bahwa ikatan antara serat dan matrik tidak begitu bagus. Hal tersebut bisa diakibatkan antara lain :

- Serat yang terlalu besar
- Kadar air dalam serat
- Serat kotor
- *Void-void* yang timbul diantara serat dan matrik

4.6 Keunggulan Dan Kekurangan

Berikut ini adalah beberapa keunggulan dari material komposit yang telah dibuat ini :

- Ringan karena memiliki densitas yang rendah
- Memiliki tampilan yang transparan
- Memiliki sifat *insulator thermal* dan *electric* yang baik
- Pembuatan bisa dibentuk tergantung *moulding* nya
- Ramah lingkungan

Berikut ini adalah beberapa kekurangan dari material komposit yang telah dibuat ini :

- Kekuatan tidak setara dan lebih lemah dari logam
- Hanya mampu proses gergaji dan proses bor
- Tidak bisa dilakukan pengelasan

4.7 Keuntungan Dan Kerugian

Berikut ini adalah beberapa keuntungan dari material komposit yang telah dibuat ini :

- Kebutuhan serat yang tersedia mudah didapat dan tidak memerlukan biaya
- Alat pembuatan yang sederhana

Berikut ini adalah kerugian dari material komposit yang telah dibuat ini :

- Harga resin yang cukup mahal

BAB V
KESIMPULAN DAN SARAN

5.1. Kesimpulan

Setelah melakukan analisis dan perhitungan dari data dan hasil pengujian tentang pengaruh variasi panjang serat jerami terhadap material komposit jerami-epoksi dapat disimpulkan antara lain :

1. Pada material komposit penggunaan panjang serat 30 mm lebih kuat dari pada 20 mm, itu dilihat dari harga paling besar yaitu pada kekuatan tarik 19,68 MPa dan pada kekuatan bending 98,9 MPa.
2. Modulus elastisitas tarik dan bending paling besar dimiliki oleh material komposit dengan panjang serat 20 mm yaitu 494,57 MPa dan 3861 MPa.
3. Fraksi volume awal 50% pada material komposit tidak mencapai hasil yang direncanakan karena hanya mencapai 35%, itu disebabkan pada saat proses pembuatan hanya menggunakan alat sederhana.
4. Adanya *void-void* pada spesimen diakibatkan pada saat proses pembuatan dilakukan dengan cara yang kurang benar.

5. Faktor serat diantaranya diameter serat, panjang serat, kadar air pada serat dan cara pembersihan pada serat berpengaruh pada kekuatan ikatan antara serat dan matrik.

5.2. Saran

Setelah melakukan penelitian dan menyimpulkan hasil penelitian maka disarankan :

1. Jika dilakukan pengembangan pada material ini lakukanlah antara lain :
   a. Memvariasikan fraksi volume
   b. Memvariasikan orientasi serat
   c. Memvariasikan kadar air pada serat
   d. Pilihlah dimensi paling kecil, terutama diameternya
   e. Pengunaan matrik selain resin epoksi
   f. Menambahkan pengujian mekanik berupa pengujian impak
   g. Lakukan foto struktur mikro atau makro.
2. Gunakan alat-alat pembuatan yang mendukung atau sesuai agar proses pembuatan bisa lebih baik dan hasil lebih memuaskan.

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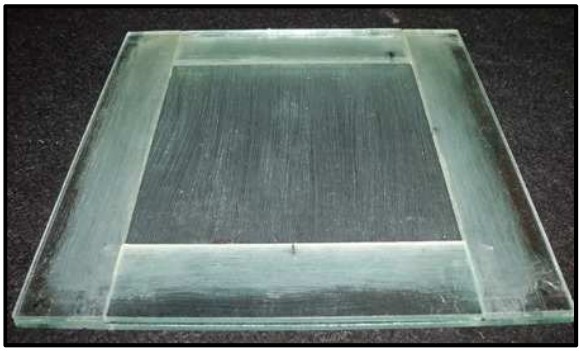
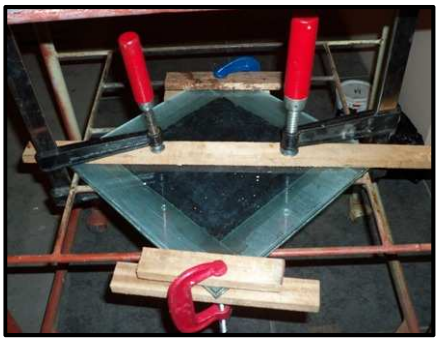
LAMPIRAN

A. Foto Proses Pembuatan



Cetakan kaca yang telah dilapisi wax.

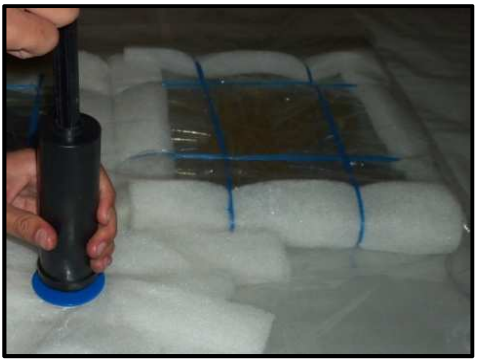
Cetakan yang telah di isi jerami dan resin epoksi.



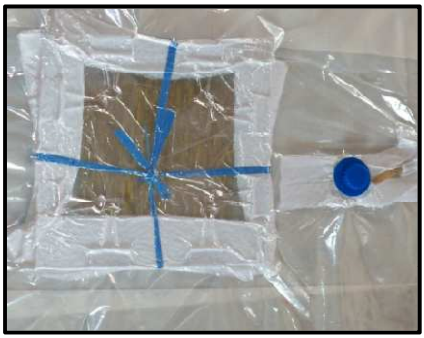
Proses pengepresan dengan klem.

Klip digunakan sebagai pengganti klem.

Cetakan yang telah dibungkus dengan busa.



Proses penghisapan udara keluar dari vacuum bag.

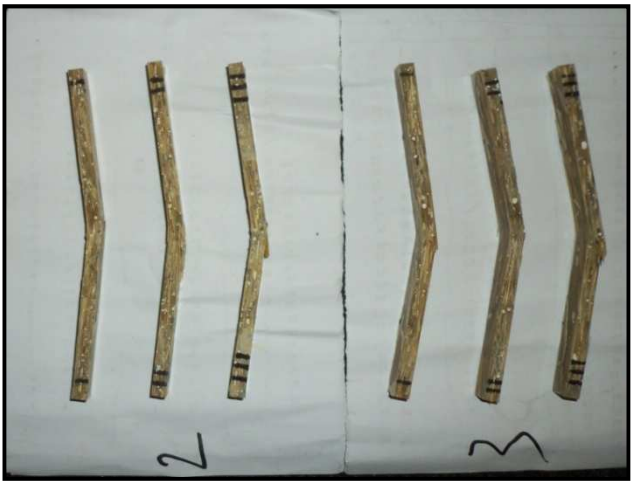


Cetakan yang berada dalam vacumm bag yang telah dihisap udaranya.

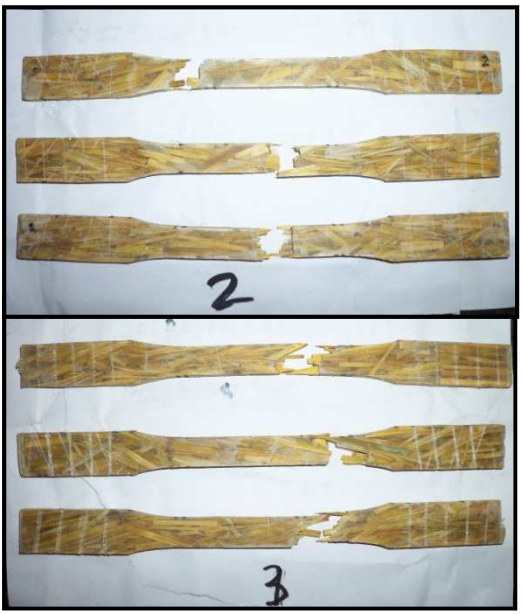
Spesimen pengujian bending.

Spesimen pengujian tarik.

B. Foto Spesimen Setelah Pengujan



Spesimen Bending.



Spesimen Tarik.

C. Uji Densitas Serat

Massa jenis/densitas suatu material merupakan perbandingan antara berat dan volume dari material tersebut. Dalam menentukan massa jenis suatu benda yang bentuknya beraturan dapat mudah kita lakukan dengan menggunakan persamaan 2.1 (Tipler, 1991).

$$\rho = \frac{m_u}{v}$$

Dimana : ρ = massa jenis (gr/cm^3)
m_u = massa material di udara (gr)
v = volume material (cm^3)

Untuk benda dengan bentuk yang tidak beraturan, dimana kita kesulitan untuk menentukan volumenya. Kita dapat menghitung massa jenis dengan hukum Archimedes, bahwa berat benda di dalam air sama dengan berat di udara dikurangi dengan gaya ke atas yang diberikan oleh air. Gaya tekan ke atas merupakan volume dari benda tersebut.

Spesimen Uji	Berat Serat (m_u) gr	v_1 ml	v_2 ml	v (v_2-v_1) ml	Masa Jenis (ρ) gr/cm^3
1	4,15	70	76	6	0,691
2	4,12	70	76	6	0,686
3	4,17	70	77	7	0,595
4	4,19	70	77	7	0,598
Jumlah Total					2,57
Masa Jenis Rata-rata					0,642

Tabel Pengolahan Pengujian densitas jerami.

D. Perhitungan Dan Analisis Fraksi Volume

Perhitungan fraksi volume (V_f) awal

Diketahui :

- Ukuran cetakan p = 20 cm
  l = 20 cm
  t = 0,6 cm

- Massa jenis serat jerami ρ_f = 0,642 gr/cm^3
- Massa jenis matrik resin epoksi ρ_m = 1,17 gr/cm^3
- Fraksi volume serat jerami (V_f) = 50 %

Volume catakan (v_c) = p x l x t
= 20 x 20 x 0,6
= 240 cm^3

Volume serat (v_f) = 50% x v_c
= 0,5 x 240 cm^3
= 120 cm^3

Berat serat (w_f) = ρ_f x v_f
= 0,642 gr/cm^3 x 120 cm^3
= 77,04 gr

Volume matrik (v_m) = 50% x v_c
= 0,5 x 240 cm^3
= 120 cm^3

Berat matrik (w_m) = ρ_m x v_m
= 1,17 gr/cm^3 x 120 cm^3
= 140,4 gr

Berat komposit (w_c) = w_f + w_m
= 77,04 + 140,4
= 217,44 gr

Analisis fraksi volume akhir

V_r (cm^3)	Vf_r (%)	ρ_r (gr/cm^3)	V_s (cm^3)	Vf_s (%)	ρ_s (gr/cm^3)	m_c (gr)	berat ditimbang (gr)
0	0	1,17	2,001	100	0,642	1,28	1,95
0,10005	5	1,17	1,90095	95	0,642	1,34	1,95
0,2001	10	1,17	1,8009	90	0,642	1,39	1,95
0,30015	15	1,17	1,70085	85	0,642	1,44	1,95
0,4002	20	1,17	1,6008	80	0,642	1,5	1,95
0,50025	25	1,17	1,50075	75	0,642	1,55	1,95
0,6003	30	1,17	1,4007	70	0,642	1,6	1,95
0,70035	35	1,17	1,30065	65	0,642	1,65	1,95
0,8004	40	1,17	1,2006	60	0,642	1,71	1,95
0,90045	45	1,17	1,10055	55	0,642	1,76	1,95
1,0005	50	1,17	1,0005	50	0,642	1,81	1,95
1,10055	55	1,17	0,90045	45	0,642	1,87	1,95
1,2006	60	1,17	0,8004	40	0,642	1,92	1,95
1,30065	**65**	**1,17**	**0,70035**	**35**	**0,642**	**1,97**	**1,95**
1,4007	70	1,17	0,6003	30	0,642	2,02	1,95
1,50075	75	1,17	0,50025	25	0,642	2,08	1,95
1,6008	80	1,17	0,4002	20	0,642	2,13	1,95
1,70085	85	1,17	0,30015	15	0,642	2,18	1,95
1,8009	90	1,17	0,2001	10	0,642	2,24	1,95
1,90095	95	1,17	0,10005	5	0,642	2,29	1,95
2,001	100	1,17	0	0	0,642	2,34	1,95

Tabel pengolahan data fraksi volume akhir material komposit serat 20 mm.

V_r (cm^3)	Vf_r (%)	ρ_r (gr/cm^3)	V_s (cm^3)	Vf_s (%)	ρs (gr/cm^3)	m_c (gr)	berat ditimbang (gr)
0	0	1,17	2,0445	100	0,642	1,31257	2
0,102225	5	1,17	1,942275	95	0,642	1,36654	2
0,20445	10	1,17	1,84005	90	0,642	1,42052	2
0,306675	15	1,17	1,737825	85	0,642	1,47449	2
0,4089	20	1,17	1,6356	80	0,642	1,52847	2
0,511125	25	1,17	1,533375	75	0,642	1,58244	2
0,61335	30	1,17	1,43115	70	0,642	1,63642	2
0,715575	35	1,17	1,328925	65	0,642	1,69039	2
0,8178	40	1,17	1,2267	60	0,642	1,74437	2
0,920025	45	1,17	1,124475	55	0,642	1,79834	2
1,02225	50	1,17	1,02225	50	0,642	1,85232	2
1,124475	55	1,17	0,920025	45	0,642	1,90629	2
1,2267	60	1,17	0,8178	40	0,642	1,96027	2
1,328925	**65**	**1,17**	**0,715575**	**35**	**0,642**	**2,01424**	**2**
1,43115	70	1,17	0,61335	30	0,642	2,06822	2
1,533375	75	1,17	0,511125	25	0,642	2,12219	2
1,6356	80	1,17	0,4089	20	0,642	2,17617	2
1,737825	85	1,17	0,306675	15	0,642	2,23014	2
1,84005	90	1,17	0,20445	10	0,642	2,28412	2
1,942275	95	1,17	0,102225	5	0,642	2,33809	2
2,0445	100	1,17	0	0	0,642	2,39207	2

Tabel pengolahan data fraksi volume akhir material komposit serat 30 mm.

E. Data Awal Pengujian Tarik

Panjang serat (mm)	Nomor spesimen (mm)	Panjang (mm)	Lebar (mm)	Tebal (mm)	Luas penampang (mm)
20	I	50	13,25	6,2	82,15
	II	50	12,95	6,25	80,94
	III	50	13,15	6,3	82,85
30	I	50	12,82	6,45	82,69
	II	50	12,77	6,45	82,37
	III	50	13,22	6,45	85,27

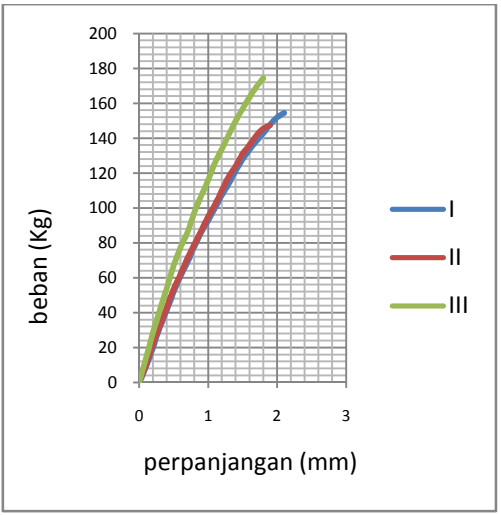
Tabel dimensi awal spesimen tarik.

Spesimen Tarik Serat 20 mm		
Spesimen	Beban Maksimum	ΔL
I	154,5 Kg	2,1 mm
II	147,5 Kg	1,9 mm
III	175 Kg	1,8 mm

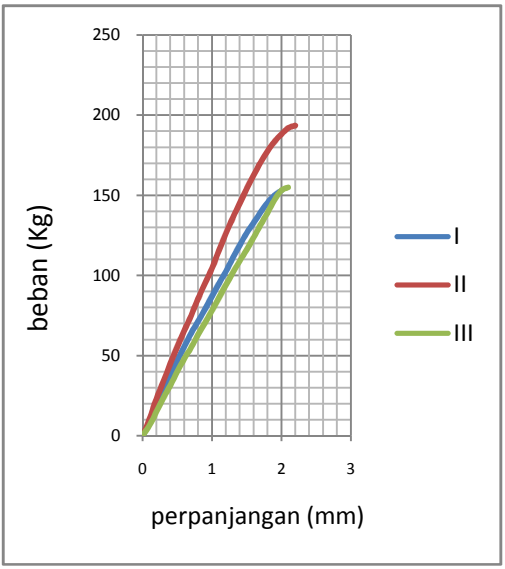
Tabel data awal pengujian tarik spesimen serat 3 cm.

Spesimen Tarik Serat 30 mm		
Spesimen	Beban Maksimum	ΔL
I	153 Kg	2 mm
II	193,5 Kg	2,1 mm
III	155 Kg	2,2 mm

Tabel data awal pengujian tarik spesimen serat 2 cm.



Grafik hasil pengujian tarik spesimen serat 2 cm.



Grafik hasil pengujian tarik spesimen serat 3 cm.

F. Contoh Perhitungan Pengujian Tarik

Spesimen I serat 20 mm

F = 154,5 Kg = 1515,64 N

L_o = 50 mm

L_1 = 52,1 mm

A = 82,15 mm^2

Tegangan Tarik

$$\sigma = \frac{F}{A} = \frac{1515,64}{82,15}$$

$$= 18,45 \text{ MPa}$$

Regangan Tarik

$$\varepsilon = \frac{l_1 - l_0}{l_0} = \frac{52,1 - 50}{50}$$

$$= 0,042$$

Modulus Elastisitas Tarik

$$E = \frac{\sigma}{\varepsilon} = \frac{18,45}{0,042}$$

$$= 439,28 \text{ MPa}$$

G. Data Awal Pengujian Bending

Panjang serat (mm)	Nomor spesimen (mm)	Lebar (mm)	Tebal (mm)	Panjang span (mm)	Luas span (mm)
20	I	15,4	6,26	80	1232
	II	15,62	6,27	80	1249,6
	III	15,77	6,27	80	1261,6
30	I	15,9	6,27	80	1272
	II	15,25	6,18	80	1220
	III	15,81	6,18	80	1264,8

Tabel dimensi awal spesimen bending.

defleksi (mm)	Spesimen Bending Serat 3 cm (Kg)		
	I	II	III
0	0	0	0
0,5	32	30,75	31
1	35,25	34,5	34,5
1,5	38,25	38	38
2	41	41,5	40,25
2,5	43,5	44	42
3	46	46	43,75
3,5	48	48	46
4	49,5	51,75	47,25
4,5	51	51,75	47,5
5	52,25	52	**47,75**
5,1	52,25	**52**	47,5
5,5	52,25	39,5	46,5
5,7	**52,25**	38,5	45,25
6	47,5	-	39,5

6,5	42		36,5
7	-		

Tabel data awal pengujian bending spesimen serat 3 cm.

defleksi	Spesimen Bending Serat 2 cm (Kg)		
(mm)	I	II	III
0	0	0	0
0,5	32,5	32	33,25
1	37	36,75	37,75
1,5	41	41	40,5
2	44	44	43
2,5	47	46,25	46,5
3	48,75	47,25	49,5
3,5	50,75	48	51,25
4	52,75	**48,5**	51,25
4,2	52,75	46	**51,25**
4,5	53,25	43	43
4,8	**53,25**	41,5	42
5	51,5	40,5	41,5
5,5	48		

Tabel data awal pengujian bending spesimen serat 2 cm.

H. Contoh Perhitungan Pengujian Bending

Spesimen I serat 20 mm

P = 53,25 Kg = 522,38 N

L = 80 mm

b =15,4 mm

d = 6, 26 mm

δ = 4,8 mm^2

Tegangan Bending

$$\sigma_b = \frac{3PL}{2bd^2} = \frac{3\ x\ 522{,}38\ x\ 80}{2\ x\ 15{,}4\ x\ (6{,}262^2)}$$

$$= 103{,}87 \text{ MPa}$$

Modulus Elastisitas Bending

$$E_b = \frac{L^3P}{4bd^3\delta} = \frac{80^3\ x\ 522{,}38}{4\ x\ 15{,}4\ x\ (6{,}26)^3\ x\ 4{,}8}$$

$$= 3687{,}34 \text{ MPa}$$

I. Data Lainnya Pada Material Komposit Setelah Jadi

Berat material komposit dengan dimensi (200x200x6)mm :

- Komposit panjang serat 20 mm = 233 gr
- Komposit panjang serat 30 mm = 234 gr

Biaya pembuatan untuk dimensi (200x200x6)mm adalah Rp 35000,- dengan rincian :

- Resin epoksi Rp 28750,-
- Larutan NaOH dan Wax Rp 6250,-

Designation: D 638 – 02

An American National Standard

Standard Test Method for Tensile Properties of Plastics[1]

This standard is issued under the fixed designation D 638; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard dumbbell-shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed.

1.2 This test method can be used for testing materials of any thickness up to 14 mm (0.55 in.). However, for testing specimens in the form of thin sheeting, including film less than 1.0 mm (0.04 in.) in thickness, Test Methods D 882 is the preferred test method. Materials with a thickness greater than 14 mm (0.55 in.) must be reduced by machining.

1.3 This test method includes the option of determining Poisson's ratio at room temperature.

NOTE 1—This test method and ISO 527-1 are technically equivalent.

NOTE 2—This test method is not intended to cover precise physical procedures. It is recognized that the constant rate of crosshead movement type of test leaves much to be desired from a theoretical standpoint, that wide differences may exist between rate of crosshead movement and rate of strain between gage marks on the specimen, and that the testing speeds specified disguise important effects characteristic of materials in the plastic state. Further, it is realized that variations in the thicknesses of test specimens, which are permitted by these procedures, produce variations in the surface-volume ratios of such specimens, and that these variations may influence the test results. Hence, where directly comparable results are desired, all samples should be of equal thickness. Special additional tests should be used where more precise physical data are needed.

NOTE 3—This test method may be used for testing phenolic molded resin or laminated materials. However, where these materials are used as electrical insulation, such materials should be tested in accordance with Test Methods D 229 and Test Method D 651.

NOTE 4—For tensile properties of resin-matrix composites reinforced with oriented continuous or discontinuous high modulus >20-GPa (>3.0 × 10^6-psi) fibers, tests shall be made in accordance with Test Method D 3039/D 3039M.

1.4 Test data obtained by this test method are relevant and appropriate for use in engineering design.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation[2]

D 412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension[3]

D 618 Practice for Conditioning Plastics for Testing[4]

D 651 Test Method for Tensile Strength of Molded Electrical Insulating Materials[5]

D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[4]

D 883 Terminology Relating to Plastics[4]

D 1822 Test Method for Tensile-Impact Energy to Break Plastics and Electrical Insulating Materials[4]

D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials[6]

D 4000 Classification System for Specifying Plastic Materials[7]

D 4066 Classification System for Nylon Injection and Extrusion Materials[7]

D 5947 Test Methods for Physical Dimensions of Solid Plastic Specimens[8]

E 4 Practices for Force Verification of Testing Machines[9]

E 83 Practice for Verification and Classification of Extensometer[9]

E 132 Test Method for Poisson's Ratio at Room Temperature[9]

E 691 Practice for Conducting an Interlaboratory Study to

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vol 09.01.

[4] *Annual Book of ASTM Standards*, Vol 08.01.

[5] Discontinued; see *1994 Annual Book of ASTM Standards*, Vol 10.01.

[6] *Annual Book of ASTM Standards*, Vol 15.03.

[7] *Annual Book of ASTM Standards*, Vol 08.02.

[8] *Annual Book of ASTM Standards*, Vol 08.03.

[9] *Annual Book of ASTM Standards*, Vol 03.01.

***A Summary of Changes section appears at the end of this standard.**

Determine the Precision of a Test Method[10]

2.2 *ISO Standard:*

ISO 527-1 Determination of Tensile Properties[11]

3. Terminology

3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D 883 and Annex A2.

4. Significance and Use

4.1 This test method is designed to produce tensile property data for the control and specification of plastic materials. These data are also useful for qualitative characterization and for research and development. For many materials, there may be a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 in Classification D 4000 lists the ASTM materials standards that currently exist.

4.2 Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled.

4.2.1 It is realized that a material cannot be tested without also testing the method of preparation of that material. Hence, when comparative tests of materials per se are desired, the greatest care must be exercised to ensure that all samples are prepared in exactly the same way, unless the test is to include the effects of sample preparation. Similarly, for referee purposes or comparisons within any given series of specimens, care must be taken to secure the maximum degree of uniformity in details of preparation, treatment, and handling.

4.3 Tensile properties may provide useful data for plastics engineering design purposes. However, because of the high degree of sensitivity exhibited by many plastics to rate of straining and environmental conditions, data obtained by this test method cannot be considered valid for applications involving load-time scales or environments widely different from those of this test method. In cases of such dissimilarity, no reliable estimation of the limit of usefulness can be made for most plastics. This sensitivity to rate of straining and environment necessitates testing over a broad load-time scale (including impact and creep) and range of environmental conditions if tensile properties are to suffice for engineering design purposes.

NOTE 5—Since the existence of a true elastic limit in plastics (as in many other organic materials and in many metals) is debatable, the propriety of applying the term "elastic modulus" in its quoted, generally accepted definition to describe the "stiffness" or "rigidity" of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are highly dependent on such factors as rate of application of stress, temperature, previous history of specimen, etc. However, stress-strain curves for plastics, determined as described in this test method, almost always show a linear region at low stresses, and a straight line drawn tangent to this portion of the curve permits calculation of an elastic modulus of the usually defined type. Such a constant is useful if its arbitrary nature and dependence on time, temperature, and similar factors are realized.

4.4 *Poisson's Ratio*—When uniaxial tensile force is applied to a solid, the solid stretches in the direction of the applied force (axially), but it also contracts in both dimensions lateral to the applied force. If the solid is homogeneous and isotropic, and the material remains elastic under the action of the applied force, the lateral strain bears a constant relationship to the axial strain. This constant, called Poisson's ratio, is defined as the negative ratio of the transverse (negative) to axial strain under uniaxial stress.

4.4.1 Poisson's ratio is used for the design of structures in which all dimensional changes resulting from the application of force need to be taken into account and in the application of the generalized theory of elasticity to structural analysis.

NOTE 6—The accuracy of the determination of Poisson's ratio is usually limited by the accuracy of the transverse strain measurements because the percentage errors in these measurements are usually greater than in the axial strain measurements. Since a ratio rather than an absolute quantity is measured, it is only necessary to know accurately the relative value of the calibration factors of the extensometers. Also, in general, the value of the applied loads need not be known accurately.

5. Apparatus

5.1 *Testing Machine*—A testing machine of the constant-rate-of-crosshead-movement type and comprising essentially the following:

5.1.1 *Fixed Member*—A fixed or essentially stationary member carrying one grip.

5.1.2 *Movable Member*—A movable member carrying a second grip.

5.1.3 *Grips*—Grips for holding the test specimen between the fixed member and the movable member of the testing machine can be either the fixed or self-aligning type.

5.1.3.1 Fixed grips are rigidly attached to the fixed and movable members of the testing machine. When this type of grip is used extreme care should be taken to ensure that the test specimen is inserted and clamped so that the long axis of the test specimen coincides with the direction of pull through the center line of the grip assembly.

5.1.3.2 Self-aligning grips are attached to the fixed and movable members of the testing machine in such a manner that they will move freely into alignment as soon as any load is applied so that the long axis of the test specimen will coincide with the direction of the applied pull through the center line of the grip assembly. The specimens should be aligned as perfectly as possible with the direction of pull so that no rotary motion that may induce slippage will occur in the grips; there is a limit to the amount of misalignment self-aligning grips will accommodate.

5.1.3.3 The test specimen shall be held in such a way that slippage relative to the grips is prevented insofar as possible. Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse single-cut file, serrations about 2.4 mm (0.09 in.) apart and about 1.6 mm (0.06 in.) deep, have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as the thermosetting materials. The serrations

[10] *Annual Book of ASTM Standards*, Vol 14.02.

[11] Available from American National Standards Institute, 25 W. 43rd St., 4th Floor, New York, NY 10036.

should be kept clean and sharp. Breaking in the grips may occur at times, even when deep serrations or abraded specimen surfaces are used; other techniques must be used in these cases. Other techniques that have been found useful, particularly with smooth-faced grips, are abrading that portion of the surface of the specimen that will be in the grips, and interposing thin pieces of abrasive cloth, abrasive paper, or plastic, or rubber-coated fabric, commonly called hospital sheeting, between the specimen and the grip surface. No. 80 double-sided abrasive paper has been found effective in many cases. An open-mesh fabric, in which the threads are coated with abrasive, has also been effective. Reducing the cross-sectional area of the specimen may also be effective. The use of special types of grips is sometimes necessary to eliminate slippage and breakage in the grips.

5.1.4 *Drive Mechanism*—A drive mechanism for imparting to the movable member a uniform, controlled velocity with respect to the stationary member, with this velocity to be regulated as specified in Section 8.

5.1.5 *Load Indicator*—A suitable load-indicating mechanism capable of showing the total tensile load carried by the test specimen when held by the grips. This mechanism shall be essentially free of inertia lag at the specified rate of testing and shall indicate the load with an accuracy of ±1 % of the indicated value, or better. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

NOTE 7—Experience has shown that many testing machines now in use are incapable of maintaining accuracy for as long as the periods between inspection recommended in Practices E 4. Hence, it is recommended that each machine be studied individually and verified as often as may be found necessary. It frequently will be necessary to perform this function daily.

5.1.6 The fixed member, movable member, drive mechanism, and grips shall be constructed of such materials and in such proportions that the total elastic longitudinal strain of the system constituted by these parts does not exceed 1 % of the total longitudinal strain between the two gage marks on the test specimen at any time during the test and at any load up to the rated capacity of the machine.

5.2 *Extension Indicator* (extensometer)—A suitable instrument shall be used for determining the distance between two designated points within the gage length of the test specimen as the specimen is stretched. For referee purposes, the extensometer must be set at the full gage length of the specimen, as shown in Fig. 1. It is desirable, but not essential, that this instrument automatically record this distance, or any change in it, as a function of the load on the test specimen or of the elapsed time from the start of the test, or both. If only the latter is obtained, load-time data must also be taken. This instrument shall be essentially free of inertia at the specified speed of testing. Extensometers shall be classified and their calibration periodically verified in accordance with Practice E 83.

5.2.1 *Modulus-of-Elasticity Measurements*—For modulus-of-elasticity measurements, an extensometer with a maximum strain error of 0.0002 mm/mm (in./in.) that automatically and continuously records shall be used. An extensometer classified by Practice E 83 as fulfilling the requirements of a B-2 classification within the range of use for modulus measurements meets this requirement.

5.2.2 *Low-Extension Measurements*—For elongation-at-yield and low-extension measurements (nominally 20 % or less), the same above extensometer, attenuated to 20 % extension, may be used. In any case, the extensometer system must meet at least Class C (Practice E 83) requirements, which include a fixed strain error of 0.001 strain or ±1.0 % of the indicated strain, whichever is greater.

5.2.3 *High-Extension Measurements*—For making measurements at elongations greater than 20 %, measuring techniques with error no greater than ±10 % of the measured value are acceptable.

5.2.4 *Poisson's Ratio*—Bi-axial extensometer or axial and transverse extensometers capable of recording axial strain and transverse strain simultaneously. The extensometers shall be capable of measuring the change in strains with an accuracy of 1 % of the relevant value or better.

NOTE 8—Strain gages can be used as an alternative method to measure axial and transverse strain; however, proper techniques for mounting strain gages are crucial to obtaining accurate data. Consult strain gage suppliers for instruction and training in these special techniques.

5.3 *Micrometers*—Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm (0.001 in.) should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: *(1)* a contact measuring pressure of 25 ± 2.5 kPa (3.6 ± 0.36 psi), *(2)* a movable circular contact foot 6.35 ± 0.025 mm (0.250 ± 0.001 in.) in diameter, and *(3)* a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm (0.0002 in.) over the entire foot area. Flatness of the foot and anvil shall conform to Test Method D 5947.

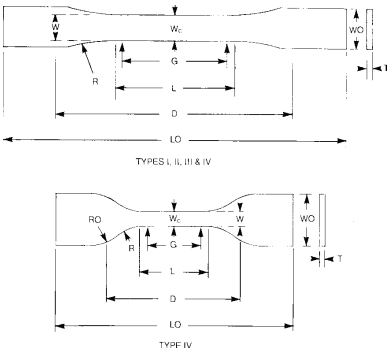
5.3.1 An optional instrument equipped with a circular contact foot 15.88 ± 0.08 mm (0.625 ± 0.003 in.) in diameter is recommended for thickness measuring of process samples or larger specimens at least 15.88 mm in minimum width.

6. Test Specimens

6.1 *Sheet, Plate, and Molded Plastics*:

6.1.1 *Rigid and Semirigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type I specimen is the preferred specimen and shall be used where sufficient material having a thickness of 7 mm (0.28 in.) or less is available. The Type II specimen may be used when a material does not break in the narrow section with the preferred Type I specimen. The Type V specimen shall be used where only limited material having a thickness of 4 mm (0.16 in.) or less is available for evaluation, or where a large number of specimens are to be exposed in a limited space (thermal and environmental stability tests, etc.). The Type IV specimen should be used when direct comparisons are required between materials in different rigidity cases (that is, nonrigid and semirigid). The Type III specimen must be used for all materials with a thickness of greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.2 *Nonrigid Plastics*—The test specimen shall conform to the dimensions shown in Fig. 1. The Type IV specimen shall



Specimen Dimensions for Thickness, *T*, mm (in.)[A]

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

[A] Thickness, *T*, shall be 3.2± 0.4 mm (0.13 ± 0.02 in.) for all types of molded specimens, and for other Types I and II specimens where possible. If specimens are machined from sheets or plates, thickness, *T*, may be the thickness of the sheet or plate provided this does not exceed the range stated for the intended specimen type. For sheets of nominal thickness greater than 14 mm (0.55 in.) the specimens shall be machined to 14 ± 0.4 mm (0.55 ± 0.02 in.) in thickness, for use with the Type III specimen. For sheets of nominal thickness between 14 and 51 mm (0.55 and 2 in.) approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined, and the location of the specimen with reference to the original thickness of the sheet shall be noted. Tolerances on thickness less than 14 mm (0.55 in.) shall be those standard for the grade of material tested.

[B] For the Type IV specimen, the internal width of the narrow section of the die shall be 6.00 ± 0.05 mm (0.250± 0.002 in.). The dimensions are essentially those of Die C in Test Methods D 412.

[C] The Type V specimen shall be machined or die cut to the dimensions shown, or molded in a mold whose cavity has these dimensions. The dimensions shall be:
W = 3.18 ± 0.03 mm (0.125 ± 0.001 in.),
L = 9.53 ± 0.08 mm (0.375 ± 0.003 in.),
G = 7.62 ± 0.02 mm (0.300 ± 0.001 in.), and
R = 12.7 ± 0.08 mm (0.500 ± 0.003 in.).
The other tolerances are those in the table.

[D] Supporting data on the introduction of the L specimen of Test Method D 1822 as the Type V specimen are available from ASTM Headquarters. Request RR:D20-1038.

[E] The width at the center W_c shall be +0.00 mm, −0.10 mm (+0.000 in., −0.004 in.) compared with width *W* at other parts of the reduced section. Any reduction in *W* at the center shall be gradual, equally on each side so that no abrupt changes in dimension result.

[F] For molded specimens, a draft of not over 0.13 mm (0.005 in.) may be allowed for either Type I or II specimens 3.2 mm (0.13 in.) in thickness, and this should be taken into account when calculating width of the specimen. Thus a typical section of a molded Type I specimen, having the maximum allowable draft, could be as follows:

[G] Overall widths greater than the minimum indicated may be desirable for some materials in order to avoid breaking in the grips.

[H] Overall lengths greater than the minimum indicated may be desirable either to avoid breaking in the grips or to satisfy special test requirements.

[I] Test marks or initial extensometer span.

[J] When self-tightening grips are used, for highly extensible polymers, the distance between grips will depend upon the types of grips used and may not be critical if maintained uniform once chosen.

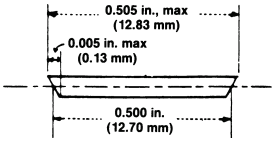


FIG. 1 Tension Test Specimens for Sheet, Plate, and Molded Plastics

be used for testing nonrigid plastics with a thickness of 4 mm (0.16 in.) or less. The Type III specimen must be used for all materials with a thickness greater than 7 mm (0.28 in.) but not more than 14 mm (0.55 in.).

6.1.3 *Reinforced Composites*—The test specimen for reinforced composites, including highly orthotropic laminates, shall conform to the dimensions of the Type I specimen shown in Fig. 1.

6.1.4 *Preparation*—Test specimens shall be prepared by machining operations, or die cutting, from materials in sheet, plate, slab, or similar form. Materials thicker than 14 mm (0.55 in.) must be machined to 14 mm (0.55 in.) for use as Type III specimens. Specimens can also be prepared by molding the material to be tested.

NOTE 9—Test results have shown that for some materials such as glass cloth, SMC, and BMC laminates, other specimen types should be considered to ensure breakage within the gage length of the specimen, as mandated by 7.3.

NOTE 10—When preparing specimens from certain composite laminates such as woven roving, or glass cloth, care must be exercised in cutting the specimens parallel to the reinforcement. The reinforcement will be significantly weakened by cutting on a bias, resulting in lower laminate properties, unless testing of specimens in a direction other than parallel with the reinforcement constitutes a variable being studied.

NOTE 11—Specimens prepared by injection molding may have different tensile properties than specimens prepared by machining or die-cutting because of the orientation induced. This effect may be more pronounced in specimens with narrow sections.

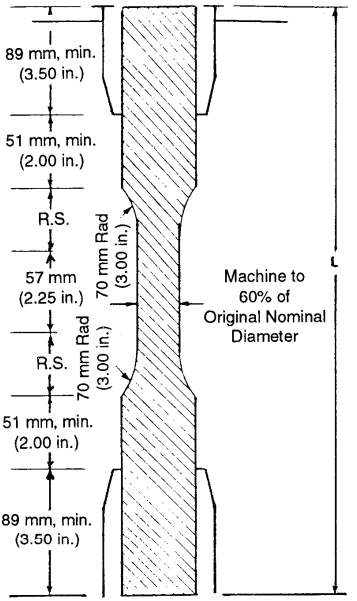
6.2 *Rigid Tubes*—The test specimen for rigid tubes shall be as shown in Fig. 2. The length, *L*, shall be as shown in the table in Fig. 2. A groove shall be machined around the outside of the specimen at the center of its length so that the wall section after machining shall be 60 % of the original nominal wall thickness. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter. Steel or brass plugs having diameters such that they will fit snugly inside the tube and having a length equal to the full jaw length plus 25 mm (1 in.) shall be placed in the ends of the specimens to prevent crushing. They can be located conveniently in the tube by separating and supporting them on a threaded metal rod. Details of plugs and test assembly are shown in Fig. 2.

6.3 *Rigid Rods*—The test specimen for rigid rods shall be as shown in Fig. 3. The length, *L*, shall be as shown in the table in Fig. 3. A groove shall be machined around the specimen at the center of its length so that the diameter of the machined portion shall be 60 % of the original nominal diameter. This groove shall consist of a straight section 57.2 mm (2.25 in.) in length with a radius of 76 mm (3 in.) at each end joining it to the outside diameter.

6.4 All surfaces of the specimen shall be free of visible flaws, scratches, or imperfections. Marks left by coarse machining operations shall be carefully removed with a fine file or abrasive, and the filed surfaces shall then be smoothed with abrasive paper (No. 00 or finer). The finishing sanding strokes shall be made in a direction parallel to the long axis of the test specimen. All flash shall be removed from a molded specimen, taking great care not to disturb the molded surfaces. In machining a specimen, undercuts that would exceed the dimensional tolerances shown in Fig. 1 shall be scrupulously avoided. Care shall also be taken to avoid other common machining errors.

6.5 If it is necessary to place gage marks on the specimen, this shall be done with a wax crayon or India ink that will not affect the material being tested. Gage marks shall not be scratched, punched, or impressed on the specimen.

6.6 When testing materials that are suspected of anisotropy, duplicate sets of test specimens shall be prepared, having their long axes respectively parallel with, and normal to, the suspected direction of anisotropy.



DIMENSIONS OF ROD SPECIMENS

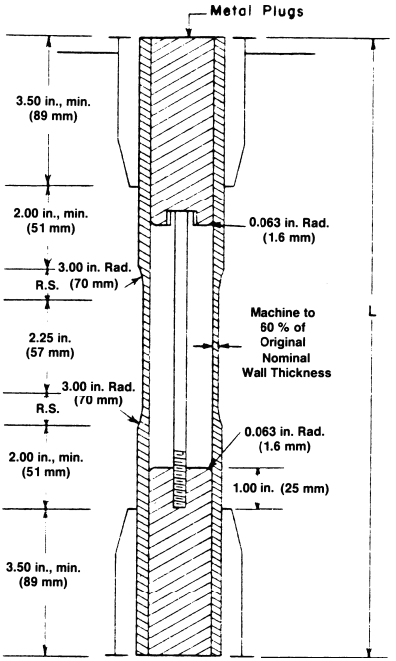
Nominal Diameter	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to Be Used for 89-mm (3½-in.) Jaws[A]
	mm (in.)		
3.2 (⅛)	19.6 (0.773)	356 (14.02)	381 (15)
4.7 (3/16)	24.0 (0.946)	361 (14.20)	381 (15)
6.4 (¼)	27.7 (1.091)	364 (14.34)	381 (15)
9.5 (⅜)	33.9 (1.333)	370 (14.58)	381 (15)
12.7 (½)	39.0 (1.536)	376 (14.79)	400 (15.75)
15.9 (⅝)	43.5 (1.714)	380 (14.96)	400 (15.75)
19.0 (¾)	47.6 (1.873)	384 (15.12)	400 (15.75)
22.2 (⅞)	51.5 (2.019)	388 (15.27)	400 (15.75)
25.4 (1)	54.7 (2.154)	391 (15.40)	419 (16.5)
31.8 (1¼)	60.9 (2.398)	398 (15.65)	419 (16.5)
38.1 (1½)	66.4 (2.615)	403 (15.87)	419 (16.5)
42.5 (1¾)	71.4 (2.812)	408 (16.06)	419 (16.5)
50.8 (2)	76.0 (2.993)	412 (16.24)	432 (17)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 3 Diagram Showing Location of Rod Tension Test Specimen in Testing Machine

7. Number of Test Specimens

7.1 Test at least five specimens for each sample in the case of isotropic materials.



DIMENSIONS OF TUBE SPECIMENS

Nominal Wall Thickness	Length of Radial Sections, 2R.S.	Total Calculated Minimum Length of Specimen	Standard Length, *L*, of Specimen to Be Used for 89-mm (3.5-in.) Jaws[A]
	mm (in.)		
0.79 (1/32)	13.9 (0.547)	350 (13.80)	381 (15)
1.2 (3/64)	17.0 (0.670)	354 (13.92)	381 (15)
1.6 (1/16)	19.6 (0.773)	356 (14.02)	381 (15)
2.4 (3/32)	24.0 (0.946)	361 (14.20)	381 (15)
3.2 (1/8)	27.7 (1.091)	364 (14.34)	381 (15)
4.8 (3/16)	33.9 (1.333)	370 (14.58)	381 (15)
6.4 (1/4)	39.0 (1.536)	376 (14.79)	400 (15.75)
7.9 (5/16)	43.5 (1.714)	380 (14.96)	400 (15.75)
9.5 (3/8)	47.6 (1.873)	384 (15.12)	400 (15.75)
11.1 (7/16)	51.3 (2.019)	388 (15.27)	400 (15.75)
12.7 (1/2)	54.7 (2.154)	391 (15.40)	419 (16.5)

[A] For other jaws greater than 89 mm (3.5 in.), the standard length shall be increased by twice the length of the jaws minus 178 mm (7 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (0.25 to 0.50 in.) in each jaw while maintaining the maximum length of the jaw grip.

FIG. 2 Diagram Showing Location of Tube Tension Test Specimens in Testing Machine

7.2 Test ten specimens, five normal to, and five parallel with, the principle axis of anisotropy, for each sample in the case of anisotropic materials.

7.3 Discard specimens that break at some flaw, or that break outside of the narrow cross-sectional test section (Fig. 1, dimension "L"), and make retests, unless such flaws constitute a variable to be studied.

NOTE 12—Before testing, all transparent specimens should be inspected in a polariscope. Those which show atypical or concentrated strain patterns should be rejected, unless the effects of these residual strains constitute a variable to be studied.

8. Speed of Testing

8.1 Speed of testing shall be the relative rate of motion of the grips or test fixtures during the test. The rate of motion of the driven grip or fixture when the testing machine is running idle may be used, if it can be shown that the resulting speed of testing is within the limits of variation allowed.

8.2 Choose the speed of testing from Table 1. Determine this chosen speed of testing by the specification for the material being tested, or by agreement between those concerned. When the speed is not specified, use the lowest speed shown in Table 1 for the specimen geometry being used, which gives rupture within ½ to 5-min testing time.

8.3 Modulus determinations may be made at the speed selected for the other tensile properties when the recorder response and resolution are adequate.

8.4 Poisson's ratio determinations shall be made at the same speed selected for modulus determinations.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Practice D 618, unless otherwise specified by contract or the relevant ASTM material specification. Reference pre-test conditioning, to settle disagreements, shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

9.2 *Test Conditions*—Conduct the tests at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity, unless otherwise specified by contract or the relevant ASTM material specification. Reference testing conditions, to settle disagreements,

TABLE 1 Designations for Speed of Testing[A]

Classification[B]	Specimen Type	Speed of Testing, mm/min (in./min)	Nominal Strain[C] Rate at Start of Test, mm/mm· min (in./in.·min)
Rigid and Semirigid	I, II, III rods and tubes	5 (0.2) ± 25 %	0.1
		50 (2) ± 10 %	1
		500 (20) ± 10 %	10
	IV	5 (0.2) ± 25 %	0.15
		50 (2) ± 10 %	1.5
		500 (20) ± 10 %	15
	V	1 (0.05) ± 25 %	0.1
		10 (0.5) ± 25 %	1
		100 (5)± 25 %	10
Nonrigid	III	50 (2) ± 10 %	1
		500 (20) ± 10 %	10
	IV	50 (2) ± 10 %	1.5
		500 (20) ± 10 %	15

[A] Select the lowest speed that produces rupture in ½ to 5 min for the specimen geometry being used (see 8.2).

[B] See Terminology D 883 for definitions.

[C] The initial rate of straining cannot be calculated exactly for dumbbell-shaped specimens because of extension, both in the reduced section outside the gage length and in the fillets. This initial strain rate can be measured from the initial slope of the tensile strain-versus-time diagram.

shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

10. Procedure

10.1 Measure the width and thickness of rigid flat specimens (Fig. 1) with a suitable micrometer to the nearest 0.025 mm (0.001 in.) at several points along their narrow sections. Measure the thickness of nonrigid specimens (produced by a Type IV die) in the same manner with the required dial micrometer. Take the width of this specimen as the distance between the cutting edges of the die in the narrow section. Measure the diameter of rod specimens, and the inside and outside diameters of tube specimens, to the nearest 0.025 mm (0.001 in.) at a minimum of two points 90° apart; make these measurements along the groove for specimens so constructed. Use plugs in testing tube specimens, as shown in Fig. 2.

TABLE 2 Modulus, 10^6 psi, for Eight Laboratories, Five Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	0.210	0.0089	0.071	0.025	0.201
Cellulose acetate butyrate	0.246	0.0179	0.035	0.051	0.144
Acrylic	0.481	0.0179	0.063	0.051	0.144
Glass-reinforced nylon	1.17	0.0537	0.217	0.152	0.614
Glass-reinforced polyester	1.39	0.0894	0.266	0.253	0.753

10.2 Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine. The distance between the ends of the gripping surfaces, when using flat specimens, shall be as indicated in Fig. 1. On tube and rod specimens, the location for the grips shall be as shown in Fig. 2 and Fig. 3. Tighten the grips evenly and firmly to the degree necessary to prevent slippage of the specimen during the test, but not to the point where the specimen would be crushed.

10.3 Attach the extension indicator. When modulus is being determined, a Class B-2 or better extensometer is required (see 5.2.1).

NOTE 13—Modulus of materials is determined from the slope of the linear portion of the stress-strain curve. For most plastics, this linear portion is very small, occurs very rapidly, and must be recorded automatically. The change in jaw separation is never to be used for calculating modulus or elongation.

10.3.1 *Poisson's Ratio Determination:*

10.3.1.1 When Poisson's ratio is determined, the speed of testing and the load range at which it is determined shall be the same as those used for modulus of elasticity.

10.3.1.2 Attach the transverse strain measuring device. The transverse strain measuring device must continuously measure the strain simultaneously with the axial strain measuring device.

TABLE 3 Tensile Stress at Yield, 10^3 psi, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Polypropylene	3.63	0.022	0.161	0.062	0.456
Cellulose acetate butyrate	5.01	0.058	0.227	0.164	0.642
Acrylic	10.4	0.067	0.317	0.190	0.897

TABLE 4 Elongation at Yield, %, for Eight Laboratories, Three Materials

	Mean	S_r	S_R	I_r	I_R
Cellulose acetate butyrate	3.65	0.27	0.62	0.76	1.75
Acrylic	4.89	0.21	0.55	0.59	1.56
Polypropylene	8.79	0.45	5.86	1.27	16.5

10.3.1.3 Make simultaneous measurements of load and strain and record the data. The precision of the value of Poisson's ratio will depend on the number of data points of axial and transverse strain taken.

10.4 Set the speed of testing at the proper rate as required in Section 8, and start the machine.

10.5 Record the load-extension curve of the specimen.

10.6 Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

NOTE 14—If it is desired to measure both modulus and failure properties (yield or break, or both), it may be necessary, in the case of highly extensible materials, to run two independent tests. The high magnification extensometer normally used to determine properties up to the yield point may not be suitable for tests involving high extensibility. If allowed to remain attached to the specimen, the extensometer could be permanently damaged. A broad-range incremental extensometer or hand-rule technique may be needed when such materials are taken to rupture.

11. Calculation

11.1 Toe compensation shall be made in accordance with Annex A1, unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

11.2 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load in newtons (or pounds-force) by the original minimum cross-sectional area of the specimen in square metres (or square inches). Express the result in pascals (or pounds-force per square inch) and report it to three significant figures as tensile strength at yield or tensile strength at break, whichever term is applicable. When a nominal yield or break load less than the maximum is present and applicable, it may be desirable also to calculate, in a similar manner, the corresponding tensile stress at yield or tensile stress at break and report it to three significant figures (see Note A2.8).

11.3 *Percent Elongation*—If the specimen gives a yield load that is larger than the load at break, calculate percent elongation at yield. Otherwise, calculate percent elongation at break. Do this by reading the extension (change in gage length) at the moment the applicable load is reached. Divide that extension by the original gage length and multiply by 100. Report percent elongation at yield or percent elongation at break to two significant figures. When a yield or breaking load less than the maximum is present and of interest, it is desirable to calculate and report both percent elongation at yield and percent elongation at break (see Note A2.2).

11.4 *Modulus of Elasticity*—Calculate the modulus of elasticity by extending the initial linear portion of the load-extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed using the average initial cross-sectional area

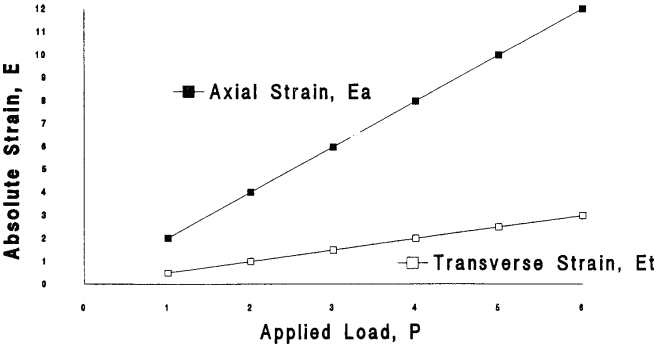


FIG. 4 Plot of Strains Versus Load for Determination of Poisson's Ratio

of the test specimens in the calculations. The result shall be expressed in pascals (pounds-force per square inch) and reported to three significant figures.

11.5 *Secant Modulus*—At a designated strain, this shall be calculated by dividing the corresponding stress (nominal) by the designated strain. Elastic modulus values are preferable and shall be calculated whenever possible. However, for materials where no proportionality is evident, the secant value shall be calculated. Draw the tangent as directed in A1.3 and Fig. A1.2, and mark off the designated strain from the yield point where the tangent line goes through zero stress. The stress to be used in the calculation is then determined by dividing the load-extension curve by the original average cross-sectional area of the specimen.

11.6 *Poisson's Ratio*—The axial strain, ϵ_a, indicated by the axial extensometer, and the transverse strain, ϵ, indicated by the transverse extensometers, are plotted against the applied load, P, as shown in Fig. 4. A straight line is drawn through each set of points, and the slopes, $d\epsilon_a / dP$ and $d\epsilon_t / dP$, of these lines are determined. Poisson's ratio, μ, is then calculated as follows:

$$\mu = -(d\epsilon_t / dP)/(d\epsilon_a / dP) \quad (1)$$

where:
$d\epsilon_t$ = change in transverse strain,
$d\epsilon_a$ = change in axial strain, and
dP = change in applied load;
or

$$\mu = -(d\epsilon_t) / (d\epsilon_a) \quad (2)$$

11.6.1 The errors that may be introduced by drawing a straight line through the points can be reduced by applying the method of least squares.

11.7 For each series of tests, calculate the arithmetic mean of all values obtained and report it as the "average value" for the particular property in question.

11.8 Calculate the standard deviation (estimated) as follows and report it to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2) / (n - 1)} \quad (3)$$

where:
s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

11.9 See Annex A1 for information on toe compensation.

TABLE 5 Tensile Strength at Break, 10^3 psi, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Polypropylene	2.97	1.54	1.65	4.37	4.66
Cellulose acetate butyrate	4.82	0.058	0.180	0.164	0.509
Acrylic	9.09	0.452	0.751	1.27	2.13
Glass-reinforced polyester	20.8	0.233	0.437	0.659	1.24
Glass-reinforced nylon	23.6	0.277	0.698	0.784	1.98

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

TABLE 6 Elongation at Break, %, for Eight Laboratories, Five Materials[A]

	Mean	S_r	S_R	I_r	I_R
Glass-reinforced polyester	3.68	0.20	2.33	0.570	6.59
Glass-reinforced nylon	3.87	0.10	2.13	0.283	6.03
Acrylic	13.2	2.05	3.65	5.80	10.3
Cellulose acetate butyrate	14.1	1.87	6.62	5.29	18.7
Polypropylene	293.0	50.9	119.0	144.0	337.0

[A] Tensile strength and elongation at break values obtained for unreinforced propylene plastics generally are highly variable due to inconsistencies in necking or "drawing" of the center section of the test bar. Since tensile strength and elongation at yield are more reproducible and relate in most cases to the practical usefulness of a molded part, they are generally recommended for specification purposes.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code numbers, form, principal dimensions, previous history, etc.,

12.1.2 Method of preparing test specimens,

12.1.3 Type of test specimen and dimensions,

TABLE 7 Tensile Yield Strength, for Ten Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1544	52.4	64.0	146.6	179.3
LDPE	20	1894	53.1	61.2	148.7	171.3
LLDPE	20	1879	74.2	99.9	207.8	279.7
LLDPE	20	1791	49.2	75.8	137.9	212.3
LLDPE	20	2900	55.5	87.9	155.4	246.1
LLDPE	20	1730	63.9	96.0	178.9	268.7
HDPE	2	4101	196.1	371.9	549.1	1041.3
HDPE	2	3523	175.9	478.0	492.4	1338.5

12.1.4 Conditioning procedure used,

12.1.5 Atmospheric conditions in test room,

12.1.6 Number of specimens tested,

12.1.7 Speed of testing,

12.1.8 Classification of extensometers used. A description of measuring technique and calculations employed instead of a minimum Class-C extensometer system,

12.1.9 Tensile strength at yield or break, average value, and standard deviation,

12.1.10 Tensile stress at yield or break, if applicable, average value, and standard deviation,

12.1.11 Percent elongation at yield or break, or both, as applicable, average value, and standard deviation,

12.1.12 Modulus of elasticity, average value, and standard deviation,

12.1.13 Date of test, and

12.1.14 Revision date of Test Method D 638.

13. Precision and Bias [12]

13.1 *Precision*—Tables 2-6 are based on a round-robin test conducted in 1984, involving five materials tested by eight laboratories using the Type I specimen, all of nominal 0.125-in. thickness. Each test result was based on five individual determinations. Each laboratory obtained two test results for each material.

TABLE 8 Tensile Yield Elongation, for Eight Laboratories, Eight Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	17.0	1.26	3.16	3.52	8.84
LDPE	20	14.6	1.02	2.38	2.86	6.67
LLDPE	20	15.7	1.37	2.85	3.85	7.97
LLDPE	20	16.6	1.59	3.30	4.46	9.24
LLDPE	20	11.7	1.27	2.88	3.56	8.08
LLDPE	20	15.2	1.27	2.59	3.55	7.25
HDPE	2	9.27	1.40	2.84	3.91	7.94
HDPE	2	9.63	1.23	2.75	3.45	7.71

13.1.1 Tables 7-10 are based on a round-robin test conducted by the polyolefin subcommittee in 1988, involving eight polyethylene materials tested in ten laboratories. For each material, all samples were molded at one source, but the individual specimens were prepared at the laboratories that tested them. Each test result was the average of five individual determinations. Each laboratory obtained three test results for each material. Data from some laboratories could not be used for various reasons, and this is noted in each table.

TABLE 9 Tensile Break Strength, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in psi Units				
		Average	S_r	S_R	r	R
LDPE	20	1592	52.3	74.9	146.4	209.7
LDPE	20	1750	66.6	102.9	186.4	288.1
LLDPE	20	4379	127.1	219.0	355.8	613.3
LLDPE	20	2840	78.6	143.5	220.2	401.8
LLDPE	20	1679	34.3	47.0	95.96	131.6
LLDPE	20	2660	119.1	166.3	333.6	465.6

TABLE 10 Tensile Break Elongation, for Nine Laboratories, Six Materials

Material	Test Speed, in./min	Values Expressed in Percent Units				
		Average	S_r	S_R	r	R
LDPE	20	567	31.5	59.5	88.2	166.6
LDPE	20	569	61.5	89.2	172.3	249.7
LLDPE	20	890	25.7	113.8	71.9	318.7
LLDPE	20	64.4	6.68	11.7	18.7	32.6
LLDPE	20	803	25.7	104.4	71.9	292.5
LLDPE	20	782	41.6	96.7	116.6	270.8

13.1.2 In Tables 2-10, for the materials indicated, and for test results that derived from testing five specimens:

13.1.2.1 S_r is the within-laboratory standard deviation of the average; $I_r = 2.83\ S_r$. (See 13.1.2.3 for application of I_r.)

13.1.2.2 S_R is the between-laboratory standard deviation of the average; $I_R = 2.83\ S_R$. (See 13.1.2.4 for application of I_R.)

13.1.2.3 *Repeatability*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, those test results should be judged not equivalent if they differ by more than the I_r value for that material and condition.

13.1.2.4 *Reproducibility*—In comparing two test results for the same material, obtained by different operators using different equipment on different days, those test results should be judged not equivalent if they differ by more than the I_R value for that material and condition. (This applies between different laboratories or between different equipment within the same laboratory.)

13.1.2.5 Any judgment in accordance with 13.1.2.3 and 13.1.2.4 will have an approximate 95 % (0.95) probability of being correct.

13.1.2.6 Other formulations may give somewhat different results.

13.1.2.7 For further information on the methodology used in this section, see Practice E 691.

13.1.2.8 The precision of this test method is very dependent upon the uniformity of specimen preparation, standard practices for which are covered in other documents.

13.2 *Bias*—There are no recognized standards on which to base an estimate of bias for this test method.

[12] Supporting data are available from ASTM Headquarters. Request RR:D20-1125 for the 1984 round robin and RR:D20-1170 for the 1988 round robin.

14. Keywords

14.1 modulus of elasticity; percent elongation; plastics; tensile properties; tensile strength

ANNEXES

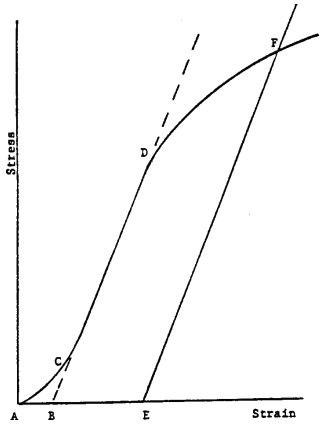
(Mandatory Information)

A1. TOE COMPENSATION

A1.1 In a typical stress-strain curve (Fig. A1.1) there is a toe region, *AC*, that does not represent a property of the material. It is an artifact caused by a takeup of slack and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

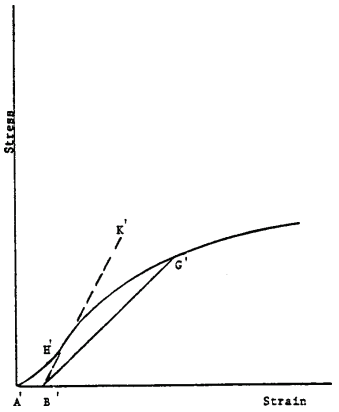
A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (Fig. A1.1), a continuation of the linear (*CD*) region of the curve is constructed through the zero-stress axis. This intersection (*B*) is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset (*BE*), if applicable. The elastic modulus can be determined by dividing the stress at any point along the line *CD* (or its extension) by the strain at the same point (measured from Point *B*, defined as zero-strain).

A1.3 In the case of a material that does not exhibit any linear region (Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection point (*H′*). This is extended to intersect the strain axis at Point *B′*, the corrected zero-strain point. Using Point *B′* as zero strain, the stress at any point (*G′*) on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B′ G′*). For those materials with no linear region, any attempt to use the tangent through the inflection point as a basis for determination of an offset yield point may result in unacceptable error.



NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region



NOTE 1—Some chart recorders plot the mirror image of this graph.

FIG. A1.2 Material with No Hookean Region

A2. DEFINITIONS OF TERMS AND SYMBOLS RELATING TO TENSION TESTING OF PLASTICS

A2.1 *elastic limit*—the greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress. It is expressed in force per unit area, usually pounds-force per square inch (megapascals).

NOTE A2.1—Measured values of proportional limit and elastic limit vary greatly with the sensitivity and accuracy of the testing equipment, eccentricity of loading, the scale to which the stress-strain diagram is plotted, and other factors. Consequently, these values are usually replaced by yield strength.

A2.2 *elongation*—the increase in length produced in the gage length of the test specimen by a tensile load. It is expressed in units of length, usually inches (millimetres). (Also known as *extension*.)

NOTE A2.2—Elongation and strain values are valid only in cases where uniformity of specimen behavior within the gage length is present. In the case of materials exhibiting necking phenomena, such values are only of qualitative utility after attainment of yield point. This is due to inability to ensure that necking will encompass the entire length between the gage marks prior to specimen failure.

A2.3 *gage length*—the original length of that portion of the specimen over which strain or change in length is determined.

A2.4 *modulus of elasticity*—the ratio of stress (nominal) to corresponding strain below the proportional limit of a material. It is expressed in force per unit area, usually megapascals (pounds-force per square inch). (Also known as *elastic modulus* or *Young's modulus*).

NOTE A2.3—The stress-strain relations of many plastics do not conform to Hooke's law throughout the elastic range but deviate therefrom even at stresses well below the elastic limit. For such materials the slope of the tangent to the stress-strain curve at a low stress is usually taken as the modulus of elasticity. Since the existence of a true proportional limit in plastics is debatable, the propriety of applying the term "modulus of elasticity" to describe the stiffness or rigidity of a plastic has been seriously questioned. The exact stress-strain characteristics of plastic materials are very dependent on such factors as rate of stressing, temperature, previous specimen history, etc. However, such a value is useful if its arbitrary nature and dependence on time, temperature, and other factors are realized.

A2.5 *necking*—the localized reduction in cross section which may occur in a material under tensile stress.

A2.6 *offset yield strength*—the stress at which the strain exceeds by a specified amount (the offset) an extension of the initial proportional portion of the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.4—This measurement is useful for materials whose stress-strain curve in the yield range is of gradual curvature. The offset yield strength can be derived from a stress-strain curve as follows (Fig. A2.1):

On the strain axis lay off *OM* equal to the specified offset.

Draw *OA* tangent to the initial straight-line portion of the stress-strain curve.

Through *M* draw a line *MN* parallel to *OA* and locate the intersection of *MN* with the stress-strain curve.

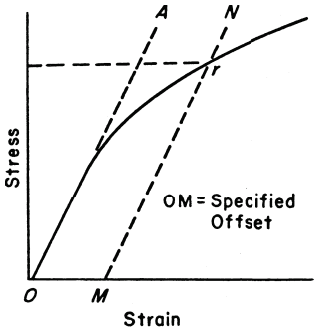


FIG. A2.1 Offset Yield Strength

The stress at the point of intersection *r* is the "offset yield strength." The specified value of the offset must be stated as a percent of the original gage length in conjunction with the strength value. *Example:* 0.1 % offset yield strength = ... MPa (psi), or yield strength at 0.1 % offset ... MPa (psi).

A2.7 *percent elongation*—the elongation of a test specimen expressed as a percent of the gage length.

A2.8 *percent elongation at break and yield:*

A2.8.1 *percent elongation at break*

the percent elongation at the moment of rupture of the test specimen.

A2.8.2 *percent elongation at yield*

the percent elongation at the moment the yield point (A2.21) is attained in the test specimen.

A2.9 *percent reduction of area (nominal)*—the difference between the original cross-sectional area measured at the point of rupture after breaking and after all retraction has ceased, expressed as a percent of the original area.

A2.10 *percent reduction of area (true)*—the difference between the original cross-sectional area of the test specimen and the minimum cross-sectional area within the gage boundaries prevailing at the moment of rupture, expressed as a percentage of the original area.

A2.11 *proportional limit*—the greatest stress which a material is capable of sustaining without any deviation from proportionality of stress to strain (Hooke's law). It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

A2.12 *rate of loading*—the change in tensile load carried by the specimen per unit time. It is expressed in force per unit time, usually newtons (pounds-force) per minute. The initial rate of loading can be calculated from the initial slope of the load versus time diagram.

A2.13 *rate of straining*—the change in tensile strain per unit time. It is expressed either as strain per unit time, usually

metres per metre (inches per inch) per minute, or percent elongation per unit time, usually percent elongation per minute. The initial rate of straining can be calculated from the initial slope of the tensile strain versus time diagram.

NOTE A2.5—The initial rate of straining is synonymous with the rate of crosshead movement divided by the initial distance between crossheads only in a machine with constant rate of crosshead movement and when the specimen has a uniform original cross section, does not "neck down," and does not slip in the jaws.

A2.14 *rate of stressing (nominal)*—the change in tensile stress (nominal) per unit time. It is expressed in force per unit area per unit time, usually megapascals (pounds-force per square inch) per minute. The initial rate of stressing can be calculated from the initial slope of the tensile stress (nominal) versus time diagram.

NOTE A2.6—The initial rate of stressing as determined in this manner has only limited physical significance. It does, however, roughly describe the average rate at which the initial stress (nominal) carried by the test specimen is applied. It is affected by the elasticity and flow characteristics of the materials being tested. At the yield point, the rate of stressing (true) may continue to have a positive value if the cross-sectional area is decreasing.

A2.15 *secant modulus*—the ratio of stress (nominal) to corresponding strain at any specified point on the stress-strain curve. It is expressed in force per unit area, usually megapascals (pounds-force per square inch), and reported together with the specified stress or strain.

NOTE A2.7—This measurement is usually employed in place of modulus of elasticity in the case of materials whose stress-strain diagram does not demonstrate proportionality of stress to strain.

A2.16 *strain*—the ratio of the elongation to the gage length of the test specimen, that is, the change in length per unit of original length. It is expressed as a dimensionless ratio.

A2.17 *tensile strength (nominal)*—the maximum tensile stress (nominal) sustained by the specimen during a tension test. When the maximum stress occurs at the yield point (A2.21), it shall be designated tensile strength at yield. When the maximum stress occurs at break, it shall be designated tensile strength at break.

A2.18 *tensile stress (nominal)*—the tensile load per unit area of minimum original cross section, within the gage boundaries, carried by the test specimen at any given moment. It is expressed in force per unit area, usually megapascals (pounds-force per square inch).

NOTE A2.8—The expression of tensile properties in terms of the minimum original cross section is almost universally used in practice. In the case of materials exhibiting high extensibility or necking, or both (A2.15), nominal stress calculations may not be meaningful beyond the yield point (A2.21) due to the extensive reduction in cross-sectional area that ensues. Under some circumstances it may be desirable to express the tensile properties per unit of minimum prevailing cross section. These properties are called true tensile properties (that is, true tensile stress, etc.).

A2.19 *tensile stress-strain curve*—a diagram in which values of tensile stress are plotted as ordinates against corresponding values of tensile strain as abscissas.

A2.20 *true strain* (see Fig. A2.2) is defined by the following equation for ϵ_T:

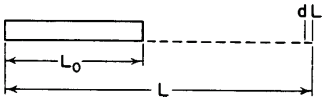


FIG. A2.2 Illustration of True Strain Equation

$$\epsilon_T = \int_{L_o}^{L} dL/L = \ln L/L_o \quad \text{(A2.1)}$$

where:

dL = increment of elongation when the distance between the gage marks is L,
L_o = original distance between gage marks, and
L = distance between gage marks at any time.

A2.21 *yield point*—the first point on the stress-strain curve at which an increase in strain occurs without an increase in stress (Fig. A2.2).

NOTE A2.9—Only materials whose stress-strain curves exhibit a point of zero slope may be considered as having a yield point.

NOTE A2.10—Some materials exhibit a distinct "break" or discontinuity in the stress-strain curve in the elastic region. This break is not a yield point by definition. However, this point may prove useful for material characterization in some cases.

A2.22 *yield strength*—the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. Unless otherwise specified, this stress will be the stress at the yield point and when expressed in relation to the tensile strength shall be designated either tensile strength at yield or tensile stress at yield as required in A2.17 (Fig. A2.3). (See *offset yield strength.*)

A2.23 *Symbols*—The following symbols may be used for the above terms:

Symbol	Term
W	Load
ΔW	Increment of load
L	Distance between gage marks at any time
L_o	Original distance between gage marks
L_u	Distance between gage marks at moment of rupture
ΔL	Increment of distance between gage marks = elongation
A	Minimum cross-sectional area at any time
A_o	Original cross-sectional area
ΔA	Increment of cross-sectional area
A_u	Cross-sectional area at point of rupture measured after breaking specimen
A_T	Cross-sectional area at point of rupture, measured at the moment of rupture
t	Time
Δt	Increment of time
σ	Tensile stress
$\Delta\sigma$	Increment of stress
σ_T	True tensile stress
σ_U	Tensile strength at break (nominal)
σ_{UT}	Tensile strength at break (true)
ϵ	Strain
$\Delta\epsilon$	Increment of strain
ϵ_U	Total strain, at break
ϵ_T	True strain
$\%El$	Percentage elongation
Y.P.	Yield point
E	Modulus of elasticity

A2.24 Relations between these various terms may be defined as follows:

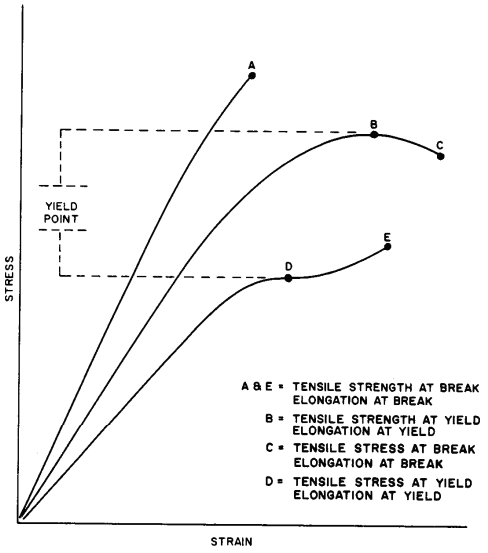


FIG. A2.3 Tensile Designations

$\sigma = W/A_o$
$\sigma_T = W/A$

$\sigma_U = W/A_o$ (where W is breaking load)
$\sigma_{UT} = W/A_T$ (where W is breaking load)
$\epsilon = \Delta L/L_o = (L - L_o)/L_o$
$\epsilon_U = (L_u - L_o)/L_o$
$\epsilon_T = \int_{L_o}^{L} dL/L = ln\ L/L_o$
$\%El = [(L - L_o)/L_o] \times 100 = \epsilon \times 100$

Percent reduction of area (nominal) = $[(A_o - A_u)/A_o] \times 100$
Percent reduction of area (true) = $[(A_o - A_T)/A_o] \times 100$
Rate of loading = $\Delta W/\Delta t$
Rate of stressing (nominal) = $\Delta\sigma/\Delta = (\Delta W]/A_o)/\Delta t$
Rate of straining = $\Delta\epsilon/\Delta t = (\Delta L/L_o)\Delta t$

For the case where the volume of the test specimen does not change during the test, the following three relations hold:

$$\sigma_T = \sigma(1 + \epsilon) = \sigma L/L_o \quad \text{(A2.2)}$$
$$\sigma_{UT} = \sigma_U(1 + \epsilon_U) = \sigma_U L_u/L_o$$
$$A = A_o/(1 + \epsilon)$$

SUMMARY OF CHANGES

This section identifies the location of selected changes to this test method. For the convenience of the user, Committee D20 has highlighted those changes that may impact the use of this test method. This section may also include descriptions of the changes or reasons for the changes, or both.

D 638–02:
(*1*) Revised 9.1 and 9.2.
D 638–01:
(*1*) Modified 7.3 regarding conditions for specimen discard.
D 638–00:
(*1*) Added 11.1 and renumbered subsequent sections.
D 638–99:
(*1*) Added and clarified extensometer classification requirements.

D 638–98:
(*1*) Revised 10.3 and added 12.1.8 to clarify extensometer usage.
(*2*) Added 12.1.14.
(*3*) Replaced reference to Test Methods D 374 with Test Method D 5947 in 2.1 and 5.3.

Designation: D 790 – 02

An American National Standard

Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[1]

This standard is issued under the fixed designation D 790; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 These test methods cover the determination of flexural properties of unreinforced and reinforced plastics, including high-modulus composites and electrical insulating materials in the form of rectangular bars molded directly or cut from sheets, plates, or molded shapes. These test methods are generally applicable to both rigid and semirigid materials. However, flexural strength cannot be determined for those materials that do not break or that do not fail in the outer surface of the test specimen within the 5.0 % strain limit of these test methods. These test methods utilize a three-point loading system applied to a simply supported beam. A four-point loading system method can be found in Test Method D 6272.

1.1.1 *Procedure A*, designed principally for materials that break at comparatively small deflections.

1.1.2 *Procedure B*, designed particularly for those materials that undergo large deflections during testing.

1.1.3 Procedure A shall be used for measurement of flexural properties, particularly flexural modulus, unless the material specification states otherwise. Procedure B may be used for measurement of flexural strength only. Tangent modulus data obtained by Procedure A tends to exhibit lower standard deviations than comparable data obtained by means of Procedure B.

1.2 Comparative tests may be run in accordance with either procedure, provided that the procedure is found satisfactory for the material being tested.

1.3 The values stated in SI units are to be regarded as the standard. The values provided in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—These test methods are not technically equivalent to ISO 178.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics for Testing[2]

D 638 Test Method for Tensile Properties of Plastics[2]

D 883 Terminology Relating to Plastics[2]

D 4000 Classification System for Specifying Plastic Materials[3]

D 5947 Test Methods for Physical Dimensions of Solid Plastic Specimens[4]

D 6272 Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials by Four-Point Bending[4]

E 4 Practices for Force Verification of Testing Machines[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

3. Terminology

3.1 *Definitions*—Definitions of terms applying to these test methods appear in Terminology D 883 and Annex A1 of Test Method D 638.

4. Summary of Test Method

4.1 A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports (see Fig. 1). A support span-to-depth ratio of 16:1 shall be used unless there is reason to suspect that a larger span-to-depth ratio may be required, as may be the case for certain laminated materials (see Section 7 and Note 8 for guidance).

4.2 The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain (see 12.7) of 5.0 % is reached, whichever occurs first.

4.3 Procedure A employs a strain rate of 0.01 mm/mm/min (0.01 in./in./min) and is the preferred procedure for this test method, while Procedure B employs a strain rate of 0.10 mm/mm/min (0.10 in./in./min).

[1] These test methods are under the jurisdiction of ASTM Committee D20 on Plastics and are the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

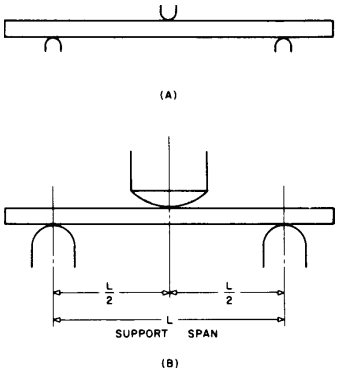
[3] *Annual Book of ASTM Standards*, Vol 08.02.

[4] *Annual Book of ASTM Standards*, Vol 08.03.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

***A Summary of Changes section appears at the end of this standard.**



NOTE—(*a*) Minimum radius = 3.2 mm (⅛ in.). (*b*) Maximum radius supports 1.6 times specimen depth; maximum radius loading nose = 4 times specimen depth.

FIG. 1 Allowable Range of Loading Nose and Support Radii

5. Significance and Use

5.1 Flexural properties as determined by these test methods are especially useful for quality control and specification purposes.

5.2 Materials that do not fail by the maximum strain allowed under these test methods (3-point bend) may be more suited to a 4-point bend test. The basic difference between the two test methods is in the location of the maximum bending moment and maximum axial fiber stresses. The maximum axial fiber stresses occur on a line under the loading nose in 3-point bending and over the area between the loading noses in 4-point bending.

5.3 Flexural properties may vary with specimen depth, temperature, atmospheric conditions, and the difference in rate of straining as specified in Procedures A and B (see also Note 8).

5.4 Before proceeding with these test methods, reference should be made to the specification of the material being tested. Any test specimen preparation, conditioning, dimensions, or testing parameters, or combination thereof, covered in the materials specification shall take precedence over those mentioned in these test methods. If there are no material specifications, then the default conditions apply. Table 1 in Classification System D 4000 lists the ASTM materials standards that currently exist for plastics.

6. Apparatus

6.1 *Testing Machine*— A properly calibrated testing machine that can be operated at constant rates of crosshead motion over the range indicated, and in which the error in the load measuring system shall not exceed ±1 % of the maximum load expected to be measured. It shall be equipped with a deflection measuring device. The stiffness of the testing machine shall be such that the total elastic deformation of the system does not exceed 1 % of the total deflection of the test specimen during testing, or appropriate corrections shall be made. The load indicating mechanism shall be essentially free from inertial lag at the crosshead rate used. The accuracy of the testing machine shall be verified in accordance with Practices E 4.

TABLE 1 Flexural Strength

Material	Mean, 10^3 psi	Values Expressed in Units of % of 10^3 psi			
		V_r[A]	V_R[B]	r[C]	R[D]
ABS	9.99	1.59	6.05	4.44	17.2
DAP thermoset	14.3	6.58	6.58	18.6	18.6
Cast acrylic	16.3	1.67	11.3	4.73	32.0
GR polyester	19.5	1.43	2.14	4.05	6.08
GR polycarbonate	21.0	5.16	6.05	14.6	17.1
SMC	26.0	4.76	7.19	13.5	20.4

[A] V_r = within-laboratory coefficient of variation for the indicated material. It is obtained by first pooling the within-laboratory standard deviations of the test results from all of the participating laboratories: $Sr = [[(s_1)^2 + (s_2)^2 \ldots + (s_n)^2]/n]^{1/2}$ then $V_r = (S_r$ divided by the overall average for the material) × 100.

[B] V_R = between-laboratory reproducibility, expressed as the coefficient of variation: $S_R = \{S_r^2 + S_L^2\}^{1/2}$ where S_L is the standard deviation of laboratory means. Then: $V_R = (S_R$ divided by the overall average for the material) × 100.

[C] r = within-laboratory critical interval between two test results = 2.8 × V_r.

[D] R = between-laboratory critical interval between two test results = 2.8 × V_R.

6.2 *Loading Noses and Supports*—The loading nose and supports shall have cylindrical surfaces. In order to avoid excessive indentation, or failure due to stress concentration directly under the loading nose, the radii of the loading nose and supports shall be 5.0 ± 0.1 mm (0.197 ± 0.004 in.) unless otherwise specified or agreed upon between the interested clients. When other loading noses and supports are used they must comply with the following requirements: they shall have a minimum radius of 3.2 mm (⅛ in.) for all specimens, and for specimens 3.2 mm or greater in depth, the radius of the supports may be up to 1.6 times the specimen depth. They shall be this large if significant indentation or compressive failure occurs. The arc of the loading nose in contact with the specimen shall be sufficiently large to prevent contact of the specimen with the sides of the nose (see Fig. 1). The maximum radius of the loading nose shall be no more than 4 times the specimen depth.

NOTE 2—Test data have shown that the loading nose and support dimensions can influence the flexural modulus and flexural strength values. The loading nose dimension has the greater influence. Dimensions of the loading nose and supports must be specified in the material specification.

6.3 *Micrometers*— Suitable micrometers for measuring the width and thickness of the test specimen to an incremental discrimination of at least 0.025 mm (0.001 in.) should be used. All width and thickness measurements of rigid and semirigid plastics may be measured with a hand micrometer with ratchet. A suitable instrument for measuring the thickness of nonrigid test specimens shall have: a contact measuring pressure of 25 ± 2.5 kPa (3.6 ± 0.36 psi), a movable circular contact foot 6.35 ± 0.025 mm (0.250 ± 0.001 in.) in diameter and a lower fixed anvil large enough to extend beyond the contact foot in all directions and being parallel to the contact foot within 0.005 mm (0.002 in.) over the entire foot area. Flatness of foot and anvil shall conform to the portion of the Calibration section of Test Methods D 5947.

7. Test Specimens

7.1 The specimens may be cut from sheets, plates, or

molded shapes, or may be molded to the desired finished dimensions. The actual dimensions used in Section 4.2, Calculation, shall be measured in accordance with Test Methods D 5947.

NOTE 3—Any necessary polishing of specimens shall be done only in the lengthwise direction of the specimen.

7.2 *Sheet Materials (Except Laminated Thermosetting Materials and Certain Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass Bonded Mica)*:

7.2.1 *Materials 1.6 mm (1⁄16 in.) or Greater in Thickness*—For flatwise tests, the depth of the specimen shall be the thickness of the material. For edgewise tests, the width of the specimen shall be the thickness of the sheet, and the depth shall not exceed the width (see Notes 4 and 5). For all tests, the support span shall be 16 (tolerance ±1) times the depth of the beam. Specimen width shall not exceed one fourth of the support span for specimens greater than 3.2 mm (⅛ in.) in depth. Specimens 3.2 mm or less in depth shall be 12.7 mm (½ in.) in width. The specimen shall be long enough to allow for overhanging on each end of at least 10 % of the support span, but in no case less than 6.4 mm (¼ in.) on each end. Overhang shall be sufficient to prevent the specimen from slipping through the supports.

NOTE 4—Whenever possible, the original surface of the sheet shall be unaltered. However, where testing machine limitations make it impossible to follow the above criterion on the unaltered sheet, one or both surfaces shall be machined to provide the desired dimensions, and the location of the specimens with reference to the total depth shall be noted. The value obtained on specimens with machined surfaces may differ from those obtained on specimens with original surfaces. Consequently, any specifications for flexural properties on thicker sheets must state whether the original surfaces are to be retained or not. When only one surface was machined, it must be stated whether the machined surface was on the tension or compression side of the beam.

NOTE 5—Edgewise tests are not applicable for sheets that are so thin that specimens meeting these requirements cannot be cut. If specimen depth exceeds the width, buckling may occur.

7.2.2 *Materials Less than 1.6 mm (1⁄16 in.) in Thickness*—The specimen shall be 50.8 mm (2 in.) long by 12.7 mm (½ in.) wide, tested flatwise on a 25.4-mm (1-in.) support span.

NOTE 6—Use of the formulas for simple beams cited in these test methods for calculating results presumes that beam width is small in comparison with the support span. Therefore, the formulas do not apply rigorously to these dimensions.

NOTE 7—Where machine sensitivity is such that specimens of these dimensions cannot be measured, wider specimens or shorter support spans, or both, may be used, provided the support span-to-depth ratio is at least 14 to 1. All dimensions must be stated in the report (see also Note 6).

7.3 *Laminated Thermosetting Materials and Sheet and Plate Materials Used for Electrical Insulation, Including Vulcanized Fiber and Glass-Bonded Mica*—For paper-base and fabric-base grades over 25.4 mm (1 in.) in nominal thickness, the specimens shall be machined on both surfaces to a depth of 25.4 mm. For glass-base and nylon-base grades, specimens over 12.7 mm (½ in.) in nominal depth shall be machined on both surfaces to a depth of 12.7 mm. The support span-to-depth ratio shall be chosen such that failures occur in the outer fibers of the specimens, due only to the bending moment (see Note 8). Therefore, a ratio larger than 16:1 may be necessary (32:1 or 40:1 are recommended). When laminated materials exhibit low compressive strength perpendicular to the laminations, they shall be loaded with a large radius loading nose (up to four times the specimen depth to prevent premature damage to the outer fibers.

7.4 *Molding Materials (Thermoplastics and Thermosets)*—The recommended specimen for molding materials is 127 by 12.7 by 3.2 mm (5 by ½by ⅛ in.) tested flatwise on a support span, resulting in a support span-to-depth ratio of 16 (tolerance ±1). Thicker specimens should be avoided if they exhibit significant shrink marks or bubbles when molded.

7.5 *High-Strength Reinforced Composites, Including Highly Orthotropic Laminates*—The span-to-depth ratio shall be chosen such that failure occurs in the outer fibers of the specimens and is due only to the bending moment (see Note 8). A span-to-depth ratio larger than 16:1 may be necessary (32:1 or 40:1 are recommended). For some highly anisotropic composites, shear deformation can significantly influence modulus measurements, even at span-to-depth ratios as high as 40:1. Hence, for these materials, an increase in the span-to-depth ratio to 60:1 is recommended to eliminate shear effects when modulus data are required, it should also be noted that the flexural modulus of highly anisotropic laminates is a strong function of ply-stacking sequence and will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

NOTE 8—As a general rule, support span-to-depth ratios of 16:1 are satisfactory when the ratio of the tensile strength to shear strength is less than 8 to 1, but the support span-to-depth ratio must be increased for composite laminates having relatively low shear strength in the plane of the laminate and relatively high tensile strength parallel to the support span.

8. Number of Test Specimens

8.1 Test at least five specimens for each sample in the case of isotropic materials or molded specimens.

8.2 For each sample of anisotropic material in sheet form, test at least five specimens for each of the following conditions. Recommended conditions are flatwise and edgewise tests on specimens cut in lengthwise and crosswise directions of the sheet. For the purposes of this test, "lengthwise" designates the principal axis of anisotropy and shall be interpreted to mean the direction of the sheet known to be stronger in flexure. "Crosswise" indicates the sheet direction known to be the weaker in flexure and shall be at 90° to the lengthwise direction.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test in accordance with Procedure A of Practice D 618 unless otherwise specified by contract or the relevant ASTM material specification. Reference pre-test conditioning, to settle disagreements, shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

9.2 *Test Conditions*—Conduct the tests at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity unless otherwise specified by contract or the relevant ASTM material specification. Reference testing conditions, to settle disagreements,

shall apply tolerances of ±1°C (1.8°F) and ±2 % relative humidity.

10. Procedure

10.1 *Procedure A*:

10.1.1 Use an untested specimen for each measurement. Measure the width and depth of the specimen to the nearest 0.03 mm (0.001 in.) at the center of the support span. For specimens less than 2.54 mm (0.100 in.) in depth, measure the depth to the nearest 0.003 mm (0.0005 in.). These measurements shall be made in accordance with Test Methods D 5947.

10.1.2 Determine the support span to be used as described in Section 7 and set the support span to within 1 % of the determined value.

10.1.3 For flexural fixtures that have continuously adjustable spans, measure the span accurately to the nearest 0.1 mm (0.004 in.) for spans less than 63 mm (2.5 in.) and to the nearest 0.3 mm (0.012 in.) for spans greater than or equal to 63 mm (2.5 in.). Use the actual measured span for all calculations. For flexural fixtures that have fixed machined span positions, verify the span distance the same as for adjustable spans at each machined position. This distance becomes the span for that position and is used for calculations applicable to all subsequent tests conducted at that position. See Annex A2 for information on the determination of and setting of the span.

10.1.4 Calculate the rate of crosshead motion as follows and set the machine for the rate of crosshead motion as calculated by Eq 1:

$$R = ZL^2/6d \quad (1)$$

where:

R = rate of crosshead motion, mm (in.)/min,
L = support span, mm (in.),
d = depth of beam, mm (in.), and
Z = rate of straining of the outer fiber, mm/mm/min (in./in./min). Z shall be equal to 0.01.

In no case shall the actual crosshead rate differ from that calculated using Eq 1, by more than ±10 %.

10.1.5 Align the loading nose and supports so that the axes of the cylindrical surfaces are parallel and the loading nose is midway between the supports. The parallelism of the apparatus may be checked by means of a plate with parallel grooves into which the loading nose and supports will fit when properly aligned (see A2.3). Center the specimen on the supports, with the long axis of the specimen perpendicular to the loading nose and supports.

10.1.6 Apply the load to the specimen at the specified crosshead rate, and take simultaneous load-deflection data. Measure deflection either by a gage under the specimen in contact with it at the center of the support span, the gage being mounted stationary relative to the specimen supports, or by measurement of the motion of the loading nose relative to the supports. Load-deflection curves may be plotted to determine the flexural strength, chord or secant modulus or the tangent modulus of elasticity, and the total work as measured by the area under the load-deflection curve. Perform the necessary toe compensation (see Annex A1) to correct for seating and indentation of the specimen and deflections in the machine.

10.1.7 Terminate the test when the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm (in./in.) or at break if break occurs prior to reaching the maximum strain (Notes 9 and 10). The deflection at which this strain will occur may be calculated by letting r equal 0.05 mm/mm (in./in.) in Eq 2:

$$D = rL^2/6d \quad (2)$$

where:

D = midspan deflection, mm (in.),
r = strain, mm/mm (in./in.),
L = support span, mm (in.), and
d = depth of beam, mm (in.).

NOTE 9—For some materials that do not yield or break within the 5 % strain limit when tested by Procedure A, the increased strain rate allowed by Procedure B (see 10.2) may induce the specimen to yield or break, or both, within the required 5 % strain limit.

NOTE 10—Beyond 5 % strain, this test method is not applicable. Some other mechanical property might be more relevant to characterize materials that neither yield nor break by either Procedure A or Procedure B within the 5 % strain limit (for example, Test Method D 638 may be considered).

10.2 *Procedure B*:

10.2.1 Use an untested specimen for each measurement.

10.2.2 Test conditions shall be identical to those described in 10.1, except that the rate of straining of the outer surface of the test specimen shall be 0.10 mm/mm (in./in.)/min.

10.2.3 If no break has occurred in the specimen by the time the maximum strain in the outer surface of the test specimen has reached 0.05 mm/mm (in./in.), discontinue the test (see Note 10).

11. Retests

11.1 Values for properties at rupture shall not be calculated for any specimen that breaks at some obvious, fortuitous flaw, unless such flaws constitute a variable being studied. Retests shall be made for any specimen on which values are not calculated.

12. Calculation

12.1 Toe compensation shall be made in accordance with Annex A1 unless it can be shown that the toe region of the curve is not due to the take-up of slack, seating of the specimen, or other artifact, but rather is an authentic material response.

12.2 *Flexural Stress* (σ_f)—When a homogeneous elastic material is tested in flexure as a simple beam supported at two points and loaded at the midpoint, the maximum stress in the outer surface of the test specimen occurs at the midpoint. This stress may be calculated for any point on the load-deflection curve by means of the following equation (see Notes 11-13):

$$\sigma_f = 3PL/2bd^2 \quad (3)$$

where:

σ = stress in the outer fibers at midpoint, MPa (psi),
P = load at a given point on the load-deflection curve, N (lbf),
L = support span, mm (in.),
b = width of beam tested, mm (in.), and

d = depth of beam tested, mm (in.).

NOTE 11—Eq 3 applies strictly to materials for which stress is linearly proportional to strain up to the point of rupture and for which the strains are small. Since this is not always the case, a slight error will be introduced if Eq 3 is used to calculate stress for materials that are not true Hookean materials. The equation is valid for obtaining comparison data and for specification purposes, but only up to a maximum fiber strain of 5 % in the outer surface of the test specimen for specimens tested by the procedures described herein.

NOTE 12—When testing highly orthotropic laminates, the maximum stress may not always occur in the outer surface of the test specimen.[7] Laminated beam theory must be applied to determine the maximum tensile stress at failure. If Eq 3 is used to calculate stress, it will yield an apparent strength based on homogeneous beam theory. This apparent strength is highly dependent on the ply-stacking sequence of highly orthotropic laminates.

NOTE 13—The preceding calculation is not valid if the specimen slips excessively between the supports.

12.3 *Flexural Stress for Beams Tested at Large Support Spans (σ_f)*—If support span-to-depth ratios greater than 16 to 1 are used such that deflections in excess of 10 % of the support span occur, the stress in the outer surface of the specimen for a simple beam can be reasonably approximated with the following equation (see Note 14):

$$\sigma_f = (3PL/2bd^2)[1 + 6(D/L)^2 - 4(d/L)(D/L)] \quad (4)$$

where:

σ_f, P, L, b, and d are the same as for Eq 3, and
D = deflection of the centerline of the specimen at the middle of the support span, mm (in.).

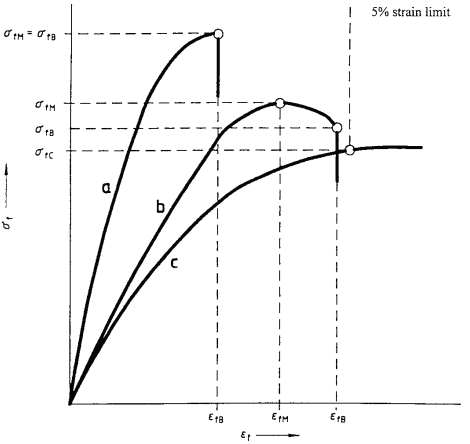
NOTE 14—When large support span-to-depth ratios are used, significant end forces are developed at the support noses which will affect the moment in a simple supported beam. Eq 4 includes additional terms that are an approximate correction factor for the influence of these end forces in large support span-to-depth ratio beams where relatively large deflections exist.

12.4 *Flexural Strength (σ_{fM})*—Maximum flexural stress sustained by the test specimen (see Note 12) during a bending test. It is calculated according to Eq 3 or Eq 4. Some materials that do not break at strains of up to 5 % may give a load deflection curve that shows a point at which the load does not increase with an increase in strain, that is, a yield point (Fig. 2, Curve B), *Y*. The flexural strength may be calculated for these materials by letting P (in Eq 3 or Eq 4) equal this point, *Y*.

12.5 *Flexural Offset Yield Strength*—Offset yield strength is the stress at which the stress-strain curve deviates by a given strain (offset) from the tangent to the initial straight line portion of the stress-strain curve. The value of the offset must be given whenever this property is calculated.

NOTE 15—This value may differ from flexural strength defined in 12.4. Both methods of calculation are described in the annex to Test Method D 638.

12.6 *Flexural Stress at Break (σ_{fB})*—Flexural stress at break of the test specimen during a bending test. It is calculated according to Eq 3 or Eq 4. Some materials may give a load deflection curve that shows a break point, *B*, without a yield point (Fig. 2, Curve a) in which case $\sigma_{fB} = \sigma_{fM}$. Other materials may give a yield deflection curve with both a yield and a break point, *B* (Fig. 2, Curve b). The flexural stress at break may be calculated for these materials by letting P (in Eq 3 or Eq 4) equal this point, *B*.



NOTE—Curve a: Specimen that breaks before yielding.
Curve b: Specimen that yields and then breaks before the 5 % strain limit.
Curve c: Specimen that neither yields nor breaks before the 5 % strain limit.

FIG. 2 Typical Curves of Flexural Stress (s_f) Versus Flexural Strain (ϵ_f)

12.7 *Stress at a Given Strain*—The stress in the outer surface of a test specimen at a given strain may be calculated in accordance with Eq 3 or Eq 4 by letting P equal the load read from the load-deflection curve at the deflection corresponding to the desired strain (for highly orthotropic laminates, see Note 12).

12.8 *Flexural Strain, ϵ_f*—Nominal fractional change in the length of an element of the outer surface of the test specimen at midspan, where the maximum strain occurs. It may be calculated for any deflection using Eq 5:

$$\epsilon_f = 6Dd/L^2 \quad (5)$$

where:

ϵ_f = strain in the outer surface, mm/mm (in./in.),
D = maximum deflection of the center of the beam, mm (in.),
L = support span, mm (in.), and
d = depth, mm (in.).
D = maximum deflection of the center of the beam, mm (in.),
L = support span, mm (in.), and

[7] For a discussion of these effects, see Zweben, C., Smith, W. S., and Wardle, M. W., "Test Methods for Fiber Tensile Strength, Composite Flexural Modulus and Properties of Fabric-Reinforced Laminates, " *Composite Materials: Testing and Design (Fifth Conference), ASTM STP 674*, 1979, pp. 228–262.

d = depth, mm (in.).

12.9 *Modulus of Elasticity*:

12.9.1 *Tangent Modulus of Elasticity*—The tangent modulus of elasticity, often called the "modulus of elasticity," is the ratio, within the elastic limit, of stress to corresponding strain. It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using Eq 6 (for highly anisotropic composites, see Note 16).

$$E_B = L^3 m / 4bd^3 \quad (6)$$

where:

E_B = modulus of elasticity in bending, MPa (psi),
L = support span, mm (in.),
b = width of beam tested, mm (in.),
d = depth of beam tested, mm (in.), and
m = slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm (lbf/in.) of deflection.

NOTE 16—Shear deflections can seriously reduce the apparent modulus of highly anisotropic composites when they are tested at low span-to-depth ratios.[7] For this reason, a span-to-depth ratio of 60 to 1 is recommended for flexural modulus determinations on these composites. Flexural strength should be determined on a separate set of replicate specimens at a lower span-to-depth ratio that induces tensile failure in the outer fibers of the beam along its lower face. Since the flexural modulus of highly anisotropic laminates is a critical function of ply-stacking sequence, it will not necessarily correlate with tensile modulus, which is not stacking-sequence dependent.

12.9.2 *Secant Modulus*— The secant modulus is the ratio of stress to corresponding strain at any selected point on the stress-strain curve, that is, the slope of the straight line that joins the origin and a selected point on the actual stress-strain curve. It shall be expressed in megapascals (pounds per square inch). The selected point is chosen at a prespecified stress or strain in accordance with the appropriate material specification or by customer contract. It is calculated in accordance with Eq 6 by letting m equal the slope of the secant to the load-deflection curve. The chosen stress or strain point used for the determination of the secant shall be reported.

12.9.3 *Chord Modulus (E_f)*—The chord modulus may be calculated from two discrete points on the load deflection curve. The selected points are to be chosen at two prespecified stress or strain points in accordance with the appropriate material specification or by customer contract. The chosen stress or strain points used for the determination of the chord modulus shall be reported. Calculate the chord modulus, E_f using the following equation:

$$E_f = (\sigma_{f2} - \sigma_{f1})/(\epsilon_{f2} - \epsilon_{f1}) \quad (7)$$

where:

σ_{f2} and σ_{f1} are the flexural stresses, calculated from Eq 3 or Eq 4 and measured at the predefined points on the load deflection curve, and ϵ_{f2} and

ϵ_{f1} are the flexural strain values, calculated from Eq 5 and measured at the predetermined points on the load deflection curve.

12.10 *Arithmetic Mean*— For each series of tests, the arithmetic mean of all values obtained shall be calculated to three significant figures and reported as the "average value" for the particular property in question.

12.11 *Standard Deviation*—The standard deviation (estimated) shall be calculated as follows and be reported to two significant figures:

$$s = \sqrt{(\Sigma X^2 - n\bar{X}^2)/(n-1)} \quad (8)$$

where:

s = estimated standard deviation,
X = value of single observation,
n = number of observations, and
$\bar{X}$ = arithmetic mean of the set of observations.

TABLE 2 Flexural Modulus

Material	Mean, 10^3 psi	Values Expressed in units of % of 10^3 psi			
		V_r[A]	V_R[B]	r[C]	R[D]
ABS	338	4.79	7.69	13.6	21.8
DAP thermoset	485	2.89	7.18	8.15	20.4
Cast acrylic	810	13.7	16.1	38.8	45.4
GR polyester	816	3.49	4.20	9.91	11.9
GR polycarbonate	1790	5.52	5.52	15.6	15.6
SMC	1950	10.9	13.8	30.8	39.1

[A] V_r = within-laboratory coefficient of variation for the indicated material. It is obtained by first pooling the within-laboratory standard deviations of the test results from all of the participating laboratories: $Sr = [[(s_1)^2 + (s_2)^2 \ldots + (s_n)^2]/n]^{1/2}$ then $V_r = (S_r$ divided by the overall average for the material) × 100.

[B] V_r = between-laboratory reproducibility, expressed as the coefficient of variation: $S_R = \{S_r^2 + S_L^2\}^{1/2}$ where S_L is the standard deviation of laboratory means. Then: $V_R = (S_R$ divided by the overall average for the material) × 100.

[C] r = within-laboratory critical interval between two test results = 2.8 × V_r.

[D] R = between-laboratory critical interval between two test results = 2.8 × V_R.

13. Report

13.1 Report the following information:

13.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form, principal dimensions, and previous history (for laminated materials, ply-stacking sequence shall be reported),

13.1.2 Direction of cutting and loading specimens, when appropriate,

13.1.3 Conditioning procedure,

13.1.4 Depth and width of specimen,

13.1.5 Procedure used (A or B),

13.1.6 Support span length,

13.1.7 Support span-to-depth ratio if different than 16:1,

13.1.8 Radius of supports and loading noses if different than 5 mm,

13.1.9 Rate of crosshead motion,

13.1.10 Flexural strain at any given stress, average value and standard deviation,

13.1.11 If a specimen is rejected, reason(s) for rejection,

13.1.12 Tangent, secant, or chord modulus in bending, average value, standard deviation, and the strain level(s) used if secant or chord modulus,

13.1.13 Flexural strength (if desired), average value, and standard deviation,

13.1.14 Stress at any given strain up to and including 5 % (if desired), with strain used, average value, and standard deviation,

13.1.15 Flexural stress at break (if desired), average value,

and standard deviation,

13.1.16 Type of behavior, whether yielding or rupture, or both, or other observations, occurring within the 5 % strain limit, and

13.1.17 Date of specific version of test used.

14. Precision and Bias [8]

14.1 Tables 1 and 2 are based on a round-robin test conducted in 1984, in accordance with Practice E 691, involving six materials tested by six laboratories using Procedure A. For each material, all the specimens were prepared at one source. Each "test result" was the average of five individual determinations. Each laboratory obtained two test results for each material.

NOTE 17—**Caution:** The following explanations of *r* and *R* (14.2-14.2.3) are intended only to present a meaningful way of considering the approximate precision of these test methods. The data given in Tables 2 and 3 should not be applied rigorously to the acceptance or rejection of materials, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of these test methods should apply the principles outlined in Practice E 691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of 14.2-14.2.3 would then be valid for such data.

14.2 *Concept of "r" and "R" in* Tables 1 and 2—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing five specimens for each test result, then:

14.2.1 *Repeatability*— Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the *r* value for that material. *r* is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

14.2.2 *Reproducibility*— Two test results obtained by different laboratories shall be judged not equivalent if they differ by more than the *R* value for that material. *R* is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

14.2.3 The judgments in 14.2.1 and 14.2.2 will have an approximately 95 % (0.95) probability of being correct.

14.3 *Bias*—No statement may be made about the bias of these test methods, as there is no standard reference material or reference test method that is applicable.

15. Keywords

15.1 flexural properties; plastics; stiffness; strength

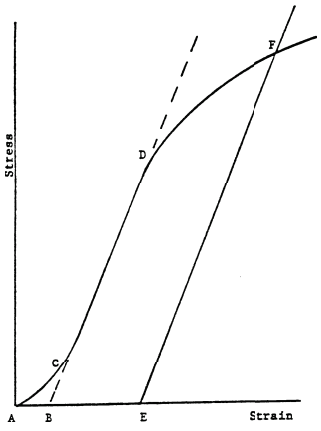
[8] Supporting data are available from ASTM Headquarters. Request RR: D20 – 1128.

ANNEXES

(Mandatory Information)

A1. TOE COMPENSATION

A1.1 In a typical stress-strain curve (see Fig. A1.1) there is a toe region, *AC,* that does not represent a property of the material. It is an artifact caused by a takeup of slack and alignment or seating of the specimen. In order to obtain correct values of such parameters as modulus, strain, and offset yield point, this artifact must be compensated for to give the corrected zero point on the strain or extension axis.

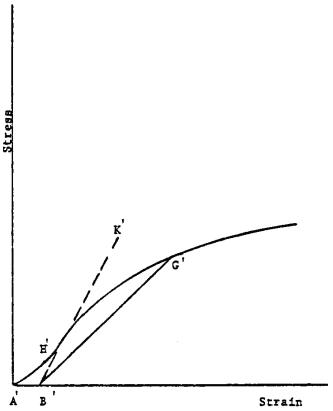


NOTE—Some chart recorders plot the mirror image of this graph.

FIG. A1.1 Material with Hookean Region

A1.2 In the case of a material exhibiting a region of Hookean (linear) behavior (see Fig. A1.1), a continuation of the linear *(CD)* region of the curve is constructed through the zero-stress axis. This intersection *(B)* is the corrected zero-strain point from which all extensions or strains must be measured, including the yield offset *(BE),* if applicable. The elastic modulus can be determined by dividing the stress at any point along the Line *CD* (or its extension) by the strain at the same point (measured from Point *B,* defined as zero-strain).

A1.3 In the case of a material that does not exhibit any linear region (see Fig. A1.2), the same kind of toe correction of the zero-strain point can be made by constructing a tangent to the maximum slope at the inflection Point *H′*. This is extended to intersect the strain axis at Point *B′,* the corrected zero-strain point. Using Point *B′* as zero strain, the stress at any point *(G′)* on the curve can be divided by the strain at that point to obtain a secant modulus (slope of Line *B′ G′).* For those materials with no linear region, any attempt to use the tangent through



NOTE—Some chart recorders plot the mirror image of this graph.

FIG. A1.2 Material with No Hookean Region

the inflection point as a basis for determination of an offset yield point may result in unacceptable error.

A2. MEASURING AND SETTING SPAN

A2.1 For flexural fixtures that have adjustable spans, it is important that the span between the supports is maintained constant or the actual measured span is used in the calculation of stress, modulus, and strain, and the loading nose or noses are positioned and aligned properly with respect to the supports. Some simple steps as follows can improve the repeatability of your results when using these adjustable span fixtures.

A2.2 Measurement of Span:

A2.2.1 This technique is needed to ensure that the correct span, not an estimated span, is used in the calculation of results.

A2.2.2 Scribe a permanent line or mark at the exact center of the support where the specimen makes complete contact. The type of mark depends on whether the supports are fixed or rotatable (see Figs. A2.1 and A2.2).

A2.2.3 Using a vernier caliper with pointed tips that is readable to at least 0.1 mm (0.004 in.), measure the distance between the supports, and use this measurement of span in the calculations.

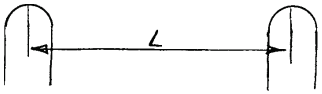


FIG. A2.1 Markings on Fixed Specimen Supports

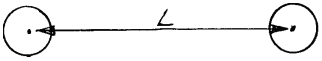


FIG. A2.2 Markings on Rotatable Specimen Supports

A2.3 *Setting the Span and Alignment of Loading Nose(s)*—To ensure a consistent day-to-day setup of the span and ensure the alignment and proper positioning of the loading nose, simple jigs should be manufactured for each of the standard setups used. An example of a jig found to be useful is shown in Fig. A2.3.

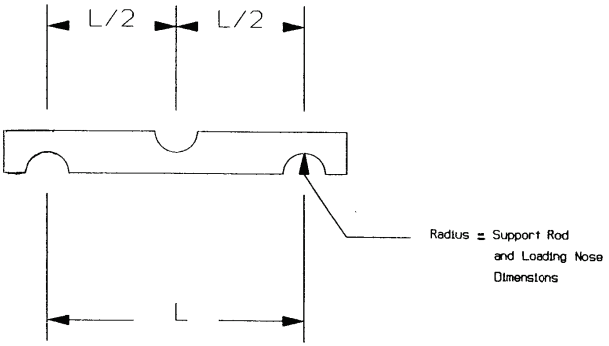


FIG. A2.3 Fixture Used to Set Loading Nose and Support Spacing and Alignment

SUMMARY OF CHANGES

This section identifies the location of selected changes to these test methods. For the convenience of the user, Committee D20 has highlighted those changes that may impact the use of these test methods. This section may also include descriptions of the changes or reasons for the changes, or both.

D 790 – 02:
(*1*) Revised 9.1 and 9.2.
D 790 – 00:
(*1*) Revised 12.1.
D 790 – 99:
(*1*) Revised 10.1.3.

D 790 – 98:
(*1*) Section 4.2 was rewritten extensively to bring this standard closer to ISO 178.
(*2*) Fig. 2 was added to clarify flexural behaviors that may be observed and to define what yielding and breaking behaviors look like, as well as the appropriate place to select these points on the stress strain curve.