Tresca stress study of CoCrMo-on-CoCrMo bearings based on body

by Sugihato -

Submission date: 27-Jul-2023 08:34AM (UTC+0700)
Submission ID: 2137335589
File name: esca_stress_study_of_CoCrMo-on-CoCrMo_bearings_based_on_body.pdf (486.63K)
Word count: 3497
Character count: 19229

Jurnal Tribologi 33 (2022) 31-38

Jurnal Tribologi

Website : jurnaltribologi.mytribos.org e-issn: 2289-7232

Tresca stress study of CoCrMo-on-CoCrMo bearings based on body mass index using 2D computational model

Muhammad Imam Ammarullah [1,2*], Gatot Santoso [1], S. Sugiharto [1], Toto Supriyono [1], Ojo Kurdi [3], Mohammad Tauviqirrahman [3], Tri Indah Winarni [2,4,5], J. Jamari [3]

[1] Department of Mechanical Engineering, Faculty of Engineering, Pasundan University, Bandung 40264, West Java, INDONESIA.
[2] Undip Biomechanics Engineering & Research Centre (UBM-ERC), Diponegoro University, Semarang 50275, Central Java, INDONESIA.
[3] Department of Mechanical Engineering, Faculty of Engineering, Diponegoro University, Semarang 50275, Central Java, INDONESIA.
[4] Department of Anatomy, Faculty of Medicine, Diponegoro University, Semarang 50275, Central Java, INDONESIA.
[5] Center for Biomedical Research (CEBIOR), Faculty of Medicine, Diponegoro University, Semarang 50275, Central Java, INDONESIA.
*Corresponding author: imamammarullah@gmail.com

KEYWORDS

Tresca stress
CoCrMo
Body mass index
2D computational model

ABSTRACT

Many investigations for developing total hip arthroplasty performance presented in previous literature show focusing on implant users' external factors. Although this is important, assessing loading based on implant user's weight also needs to be examined as it contributes to overall performance of this prosthesis. Our study attempted to evaluate Tresca stress in CoCrMo-on-CoCrMo hip implant based on body mass index from patient. 2D computational model in this paper has been establishing to reach this objective. Loading variation is also considered with different body mass index categories from underweight, normal, overweight, obese class I, obese class II, and obese class III under normal walking condition. We found that Tresca stress rises with higher body mass index category.

Received 25 July 2021; received in revised form 17 November 2021; accepted 4 February 2022.
To cite this article: Ammarullah et al. (2022). Tresca stress study of CoCrMo-on-CoCrMo bearings based on body mass index using 2D computational model. Jurnal Tribologi 33, pp.31-38.

1.0 INTRODUCTION

Hip joint replacement is one of the most successful orthopaedic surgery involving artificial hip joint to replace problematic human hip joint. Because of daily human activity, hip prosthesis obtains loads that change over period. However, anytime implants can fail caused by various mechanical aspects that threatening to its users. Failure analysis is the right choice to maximize performance of medical implants over a long period. There are two failure criteria as reference theories, von Mises and Tresa. Although von Mises can be used as a failure criterion, it is preferable to use Tresca because safety area from Tresca stress curve is smaller compared to von Mises. So, we can conclude that failure criteria with adopting Tresca are safer than von Mises (Usman and Huang, 2017). Also, several previous studies that evaluate the performance of artificial joints with Tresca have been carried out by Kaymaz et al. (Kaymaz et al., 2014), Usman and Huang (Usman and Huang, 2017), and Abdullah et al. (Abdullah et al., 2010).

Several attempts have been shown in previous papers that reporting study of total hip arthroplasty currently focus on patient's external factors, such as textured surface (Aher et al., 2020), replacement procedure (Ammarullah, 2019), material selection (Azhar et al., 2020), coating application (Shankar et al., 2018), and geometrical parameter (Basri et al., 2019a). It is important to know that user's body weight as internal factor of its implant user has a significant impact on hip implant performance. Some failure implants have reported a rising case as a more significant user's body weight (Sayed-Noor et al., 2019). Unfortunately, scientific literature presented from many researchers worldwide trending on medical perspective, but investigation regarding mechanical side of hip prosthesis based on body mass index needs further studies.

Since polyethylene wear debris from conventional metal-on-plastic bearing has been reported causing harmful effects on human body, a better option shows from using hip implant under hard-on-hard bearings due to lack of metal-on-plastic drawbacks. Hard-on-hard metallic bearing on hip prosthesis already used on hip joint replacement surgery for younger and active users, especially in Indonesia to fulfilment the needs of medical devices (Maula et al., 2021; Jamari et al., 2021). Other material, ceramic, have been several advantages compared with metal as the material option for hip bearing prosthesis provided lower wear rate and smoother contact surface. Unfortunately, there is weakness from its material's brittle properties, making some concerned to choose ceramic-on-ceramics as bearing option (Ammarullah, 2019).

To avoid high-cost experimental that require long period for total hip arthroplasty studies, computational analysis has been selected by many researchers using finite element concept (Nasution et al., 2018; Ammarullah et al., 2018). 3D finite element contact model has been conducted by Jamari et al. (Jamari et al., 2021) to study metal-on-metal hip implant, but using this model requires more time and capable hardware compared with 2D model as simplification without significantly affecting results, 2D model has been taken to solving many engineering problems, especially in medical implant. The previous researcher also adopted 2D model for ease of computation, such as Basri et al. (Basri et al., 2019a, 2019b) and Shankar et al. (Shankar et al., 2018).

This study aims to investigate Tresca stress in metal-on-metal hip implant. Finite element analysis is taken to for 2D computational investigation using vertical load according to psychological of human hip joint based on body mass index, there are underweight, normal, overweight, obese class I, obese class II, and obese class III.

2.0 MATERIALS AND METHODS

2.1 Geometry and Material

Hip prosthesis model was created by geometric data commonly used from previous study (Ammarullah et al., 2020), for femoral head diameter, radial clearance, and acetabular cup thickness there are 28 mm, 50 µm, and 5 mm respectively. Metallic material on both femoral head and acetabular cup using cobalt chromium molybdenum (CoCrMo) assumed homogeneous, isotropic, and linear elastic. Also, property of material using, there are Young's modulus of 0.3 and friction coefficient of 0.2 (Jamari et al., 2021).

2.2 Convergence Study

To create an accurate finite element model, a convergence study was carried out using the H-refinement method on the femoral head and acetabular cup components. This method is a technique for making elements smaller than the initial element size. Coarse elements can produce less accurate stress results, while fine elements will give more accurate stress distribution results. Unfortunately, meshing that is too fine will make the computation time needed to be longer. Therefore, the optimal number of elements is needed to match the time required and the accuracy of the results. The optimum number of elements we used was 5500 with 2000 CAX4 for the acetabular cup and 3500 CAX4 for the femoral head.

2.3 Finite Element Model

Computational studies in this research only consider femoral head and acetabular cup as main component following 2D ball-in-socket model for faster simulation process (Ammarullah et al., 2021b). Implementation of micro separation during contact did not consider, then contacts are carried out at steady-state conditions using ABAQUS/CAE 6.14-1. 2D model for finite element analysis is presented in Figure 1. For boundary conditions, outer acetabular cup surface is set to fix constraint and contact assuming direct-dry contact without lubrication. This simulation also considers surface roughness with coefficient friction.

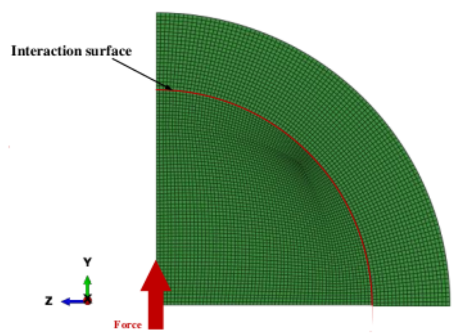

Figure 1: CoCrMo-on-CoCrMo bearing modelling using 2D finite element.

2.4 Loading Condition

Peak loading under normal walking condition has been considered as a loading scenario in conducted research referred from the measurements by Bergmann et al. (Bergmann et al., 2001). The data is then simplified by being divided into 32 phases, as was done in the previous literature

(Jamari et al., 2021; Ammarullah et al., 2021b), where the peak loading is in the 7th phase. Then, we approached the body mass index equation by making peak loading under normal walking condition into six different categories (Weisell, 2002). Mean data from patient of hip prosthesis from Bergmann et al. was 85.3 kg for body weight and 171 cm for body height included in overweight category. Approximation for getting peak loading data from other body mass index categories has conducted by assuming all categories have same body height, and then we got peak loading for all categories are 1,396 N for underweight, 1,861 N for normal, 2,326 N for overweight, 2,675 N for obese class I, 3,024 N for obese class II, and 3,373 for obese class III. Peak loading that are used in conducted simulation under normal walking condition based on body mass index is explained in Figure 2.

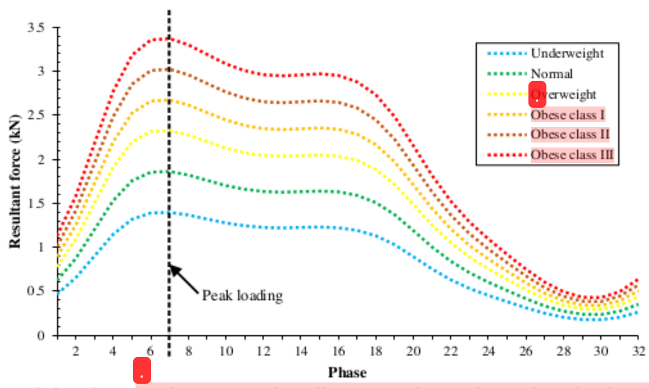

Figure 2: Peak loading under normal walking condition based on body mass index.

3.0 RESULTS AND DISCUSSION

From our computational simulation, we got Tresca stress from all of body mass index categories described in Figure 3. Peak loading at normal walking conditions is the condition when full body weight supported by human hip joint. Tresca stress for reach category based on body mass index is 45.16 MPa for underweight, 51.45 MPa for normal, 57.31 MPa for overweight, 61.54 MPa for obese class I, 65.5 MPa for obese class II, and 69.36 MPa for obese class III.

Furthermore, Figure 4 describes Tresca stress distribution at peak loading under normal walking condition for each body mass index category. It can be seen that Tresca stress value will be higher, and Tresca stress distribution will be wider in line with the greater body mass index. The order of the tresca stress distribution from the narrowest to the widest is underweight, normal, overweight, obese class I, obese class II, and obese class III.

Tresca is one of failure criteria that can be used to analyze the survival of medical implants for long period. Based on Tresca failure theory, more significant Tresca stress magnitude will reduce safety factor (Tamin and Shaffiar, 2014). Our result implies that obese users from classes I-III based on body mass index have more risk of failure in future periods. Supported from medical perspective report from Sayed-Noor et al. (Sayed-Noor et al., 2019) that explains implant patients with more significant body mass index have a greater chance to face complications after hip replacement.

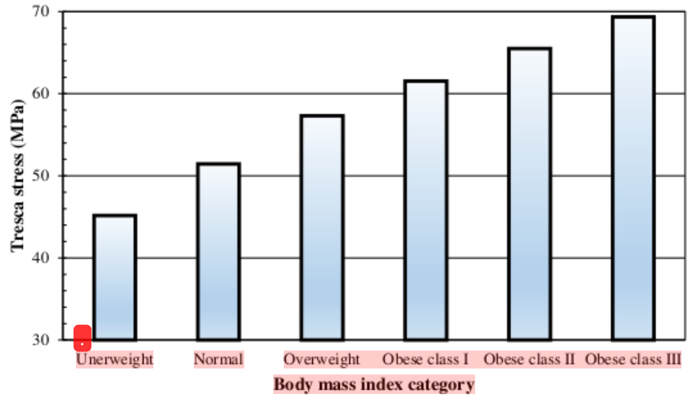

Figure 3: Highest Tresca stress of CoCrMo-on-CoCrMo bearing from various categories of body mass index.

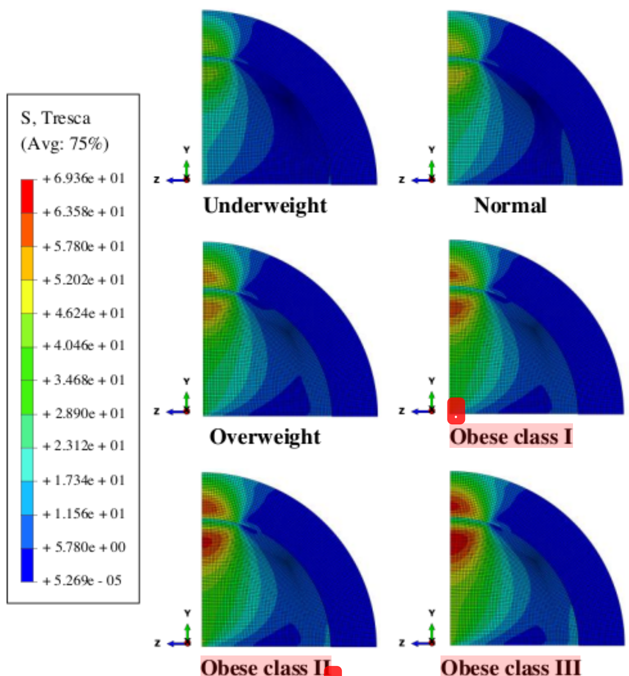

Figure 4: Highest Tresca stress distribution of CoCrMo-on-CoCrMo bearing from various categories of body mass index.

To improve the design of existing implants based on the Tresca stress values obtained, especially for obese users that having higher Tresca stress magnitude compared to other body mass index categories to reduce implant failures, it can be done by examining the external aspect from implant users. Some of these efforts. Including studying geometric parameters (Basri et al., 2019a), material selection (Azhar et al., 2020), application of surface texturing (Aher et al., 2020), and using coating in contacting surface (Shankar et al., 2018). Replacement procedures from surgeon doctor also impacted hip joint prosthesis performance (Ammarullah, 2019), where the development of surgical procedures for obese users can also be an option to reduce failure for obese people who want to perform hip joint replacement surgery. In-depth studies regarding the development of hip implants for obese patients need to be initiated.

This study has several limitations that may affect the results obtained. It is important to explain the integrity of the studies carried out. First, this study only presents data from computational simulations that need to be validated. Second, the model used is very simple in two dimensions that can reduce the accuracy of the results compared to the three-dimension model (Cilingir et al., 2007). Furthermore, the effect of the lubricating fluid is eliminated by only taking into account the coefficient of static friction that in actual conditions the coefficient of friction has a varied value over time (Nečas et al., 2020). Last but not least, if we are looking at the material used in this study, Cobalt Chromium Molybdenum (CoCrMo), which is brittle, the use of Tresca stress is not appropriate because it is more suitable for ductile materials (Tamin and Shaffiar, 2014). It is a deficiency in our research that will be improved in future studies.

CONCLUSIONS

Tresca stress study on body mass index loading effect under normal walking condition using 2D finite element representing CoCrMo-on-CoCrMo hip implant has been explained in our paper. We found that Tresca stress value rose, and Tresca stress distribution widened by increasing body mass index. Besides, Tresca stress value has relationship to implant breakdown in the future from our result. Improving implant design is necessary to avoid future failures, especially for implant users with a body mass index category of obesity (class I-III). Several ways can be done, starting from material selection, application of textured surfaces, use of coatings, the study of implant geometry, to surgical procedures specifically designed for obese people.Carried out studies to improve hip joint implant for obese user is vital to address.

ACKNOWLEDGEMENT

The research was funded by World Class Research UNDIP number 118-23/UN7.6.1/PP/2021 This work was part of research collaboration between Pasundan University and Diponegoro University.

REFERENCES

Abdullah, A.H., Asri, M.N.M., Alias, M.S., and Giha, T. (2010), Finite Element Analysis of Cemented Hip Arthroplasty: Influence of Stem Tapers, Proceedings of the International MultiConference of Engineers and Computer Scientists, III.

Aher, V.S., Shirsat, U.M., Wakchaure, V.D., and Venkatesh, M.A. (2020), An experimental investigation on tribological performance of UHMWPE composite under textured dry sliding conditions, Jurnal Tribologi, 24, 110–125.

Akbar, I., Prakoso, A.T., Astrada, Y.M., Sinaga, M.S., Ammarullah, M.I., Adanta, D., Mataram, A., Syahrom, A., Jamari, J., and Basri, H. (2021), Permeability Study of Functionally Graded Scaffold Based on Morphology of Cancellous Bone, Malaysian Journal of Medicine and Health Sciences, 17(SUPP13), 60–66.

Ammarullah, M.I., Afif, I.Y., Maula, M.I., Winarni, T.I., Tauviqirrahman, M., Akbar, I., Basri, H., Heide, E. Van Der, and Jamari, J. (2021a), Tresca Stress Simulation of Metal-on-Metal Total Hip Arthroplasty during Normal Walking Activity, Materials, 14, 7554.

Ammarullah, M.I., Afif, I.Y., Maula, M.I., Winarni, T.I., Tauviqirrahman, M., Bayuseno, A.P., Basri, H., Syahrom, A., Md Saad, A.P., and Jamari (2022a), Deformation analysis of CoCrMo-on-CoCrMo hip implant based on body mass index using 2D finite element procedure, Journal of Physics: Conference Series, 2279, 012004.

Ammarullah, M.I., Afif, I.Y., Maula, M.I., Winarni, T.I., Tauviqirrahman, M., Bayuseno, A.P., Basri, H., Syahrom, A., Saad, A.P.M., and Jamari (2022b), Wear analysis of acetabular cup on metal-on-metal total hip arthroplasty with dimple addition using finite element method, AIP Conference Proceedings, 2391, 020017.

Ammarullah, M.I., Afif, I.Y., Maula, M.I., Winarni, T.I., Tauviqirrahman, M., Bayuseno, A.P., Basri, H., Syahrom, A., Saad, A.P.M., and Jamari, J. (2021b), 2D Computational Tresca Stress Prediction of CoCrMo-on- UHMWPE Bearing of Total Hip Prosthesis Based on Body Mass Index, Malaysian Journal of Medicine and Health Sciences, 17(SUPP13), 18–21.

Ammarullah, M.I., Afif, I.Y., Maula, M.I., Winarni, T.I., Tauviqirrahman, M., and Jamari, J. (2022c), Tresca stress evaluation of Metal-on-UHMWPE total hip arthroplasty during peak loading from normal walking activity, Materials Today: Proceedings, 63, S143–S146.

Arthritis Research UK (2011), Hip replacement surgery- Patient Information, 2011th ed., Arthritis Research UK, Chesterfield, England.

Australian Orthopaedic Association National Joint Replacement Registry (2020), Annual Report 2020, 2020th ed., Australian Orthopaedic Association, Adelaide, Australia.

Azhar, A.A., Bakar, M.H.A., Tamin, N., Azlan, U.A.A., and Hassan, M.H. (2020), Friction and wear analysis of ceramic cutting tool made from alumina-zirconia-chromia, Jurnal Tribologi, 24, 27–38.

Basri, H., Syahrom, A., Prakoso, A.T., Wicaksono, D., Amarullah, M.I., Ramadhoni, T.S., and Nugraha, R.D. (2019a), The Analysis of Dimple Geometry on Artificial Hip Joint to the Performance of Lubrication, Journal of Physics: Conference Series, 1198, 042012.

Basri, H., Syahrom, A., Ramadhoni, T.S., Prakoso, A.T., Ammarullah, M.I., and Vincent (2019b), The analysis of the dimple arrangement of the artificial hip joint to the performance of lubrication, IOP Conference Series: Materials Science and Engineering, 620, 012116.

Bergmann, G., Deuretzabacher, G., Heller, M., Graichen, F., Rohlmann, A., Strauss, J., and Duda, G.N. (2001), Hip contact forces and gait patterns from routine activities, Journal of Biomechanics, 34, 859–871.

Casesnoves, F. (2021), Mathematical Standard-Parameters Dual Optimization for Metal Hip Arthroplasty Wear Modelling with Medical Physics Applications, Standards, 1, 53–66.

Cohen, E., Amougou, N., Ponty, A., Guerrien, M., Wakenge, W., Chidumwa, G., Said-Mohamed, R., Fezeu, L.K., and Pasquet, P. (2022), Direct and Indirect Determinants of Body Mass Index in Both Major Ethnic Groups Experiencing the Nutritional Transition in Cameroon, International Journal of Environmental Research and Public Health, 19, 6108.

Conradi, M., Podgornik, B., Kocijan, A., Remškar, M., and Klobčar, D. (2022), Water versus Oil Lubrication of Laser-Textured Ti6Al4V Alloy upon Addition of MoS2 Nanotubes for Green Tribology, Materials, 15, 2974.

Dassault Systèmes (2016), Abaqus Analysis User's Guide Volume IV: Elements.
EU - Indonesia Business Network (2018), EIBN Sector Reports: Medical Devices, 2018th ed., EU—Indonesia Business Network, Jakarta, Indonesia.
Fokter, S.K., Gubeljak, N., Punzón-Quijorna, E., Pelicon, P., Kelemen, M., Vavpetič, P., Predan, J., Ferlič, L., and Novak, I. (2022), Total Knee Replacement with an Uncemented Porous Tantalum Tibia Component: A Failure Analysis, Materials, 15, 2575.
Jamari, J., Ammarullah, M.I., Saad, A.P.M., Syahrom, A., Uddin, M., van der Heide, E., and Basri, H. (2021), The Effect of Bottom Profile Dimples on the Femoral Head on Wear in Metal-on-Metal Total Hip Arthroplasty, Journal of Functional Biomaterials, 12, 38.
Jamari, J., Ammarullah, M.I., Santoso, G., Sugiharto, S., Supriyono, T., Prakoso, A.T., Basri, H., and van der Heide, E. (2022), Computational Contact Pressure Prediction of CoCrMo, SS 316L and Ti6Al4V Femoral Head against UHMWPE Acetabular Cup under Gait Cycle, Journal of Functional Biomaterials, 13, 64.
Kaymaz, I., Bayrak, O., Karsan, O., Celik, A., and Alsaran, A. (2014), Failure analysis of the cement mantle in total hip arthroplasty with an efficient probabilistic method, Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 228, 409–417.
Keele University (2014), A Guide for People Who Have Osteoarthritis, 2014th ed., Keele University, Staffordshire, England.
Kosarchuk, V., Chausov, M., Pylypenko, A., Tverdomed, V., Maruschak, P., and Vasylkiv, V. (2022), Increasing Wear Resistance of Heavy-Loaded Friction Pairs by Nanoparticles in Conventional Lubricants: A Proof of Concept, Lubricants, 10, 64.
Krenzlin, H., Schmidt, L., Jankovic, D., Schulze, C., Brockmann, M.A., Ringel, F., and Keric, N. (2022), Impact of Sarcopenia and Bone Mineral Density on Implant Failure after Dorsal Instrumentation in Patients with Osteoporotic Vertebral Fractures, Medicina, 58, 748.
London Health Sciences Centre (2013), My Guide to Total Hip Joint Replacement, 2013th ed., London Health Sciences Centre, London, England.
Paterlini, A., Alexis, J., Balcaen, Y., and Bertrand, G. (2022), Cold Spraying of Thick Biomimetic and Stoichiometric Apatite Coatings for Orthopaedic Implants, Coatings, 12, 722.
Salahshour, S., Karlsen, Ø., and Lemu, H.G. (2021), Experimental and Numerical Studies of Stress Distribution in an Expanding Pin Joint System, Applied Mechanics, 3, 46–64.
Sayed-Noor, A.S., Mukka, S., Mohaddes, M., Kärrholm, J., and Rolfson, O. (2019), Body mass index is associated with risk of reoperation and revision after primary total hip arthroplasty: a study of the Swedish Hip Arthroplasty Register including 83,146 patients, Acta Orthopaedica, 90, 220–225.
Singh, T., Goswami, C., Patnaik, A., and Lendvai, L. (2022), Optimal Design of Ceramic Based Hip Implant Composites Using Hybrid AHP-MOORA Approach, Materials, 15, 3800.
Tamin, M.N., and Shaffiar, N. (2014), Solder joint reliability assessment: finite element simulation methodology.
Torabi, A.R., Shahbazian, B., Mirsayar, M., and Cicero, S. (2021), A Methodology to Determine the Effective Plastic Zone Size Around Blunt V-Notches under Mixed Mode I/II Loading and Plane-Stress Conditions, Metals, 11, 1042.
Usman, and Huang, S.C. (2017), The study of stresses characteristic of contact mechanism in total knee replacement using two-dimensional finite element analysis, Bio-Medical Materials and Engineering, 28, 567–578.
Wei, X., Liu, D., and Yin, S. (2022), An Isogeometric Bézier Finite Element Method for Vibration Optimization of Functionally Graded Plate with Local Refinement, Crystals, 12, 830.

Tresca stress study of CoCrMo-on-CoCrMo bearings based on body

ORIGINALITY REPORT

25%	20%	19%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

MATCH ALL SOURCES (ONLY SELECTED SOURCE PRINTED)

11%
★ watermark.silverchair.com
Internet Source

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		