EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 16, No. 4, October 2019, pp. 13 - 24 ISSN 2090 - 5882

(Received June 22. 2019, Accepted in final form August 25. 2019) www.egtribjournal.com

EFFECT OF SILICA NANOPARTICLES AND MULTIWALL CARBON NANOTUBES DISPERSING LUBRICATING GREASE IN METAL FORMING

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ABSTRACT

The present work discusses the influence of friction in metal forming. Experiments were carried out to determine the coefficient of friction and wear displayed by bearing steel ball sliding against aluminum (Al) sheet. The steel ball represents the die surface asperity. Lithium grease was used as lubricant and dispersed by silica (SiO_2) nano-particles and Multiwall carbon nanotubes (MWCNT).

Frictional behavior between the inner tube diameter and expanding punch surfaces was influenced the exerted load. It was proven that load slightly increased with increasing the values of friction coefficient. Friction coefficient displayed by the grease dispersed by MWCNT displayed lower values than that dispersed by silica nanoparticles. Wear resistance provided by silica nano-particles was superior to that observed for MWCNT. Grease free of additives showed the roughest surface, while the test specimen lubricated by grease dispersed by MWCNT showed severely deformed one confirming that MWCNT effect was insignificant. Surface topography of test specimen lubricated by grease dispersed by 1.0 wt. % silica nano-particles showed the finest roughness and waviness due to the rolling action of silica particles.

KEYWORDS

Silica nanoparticles, multiwall carbon nanotubes, grease, lubrication, metal forming.

INTRODUCTION

Friction between the die/workpiece surfaces influences the forming process. Increase of friction forces increases the plastic deformation of the workpiece and the work required to deform the part, [1 - 5]. The friction force generated at the interface between die and workpiece increased, the energy and forces exerted during forming will increase. Friction increases forming load, tool wear and deformation, while decreases the formability. It is different due to the high pressure, [6]. Lubrication of sheet metal forming is influenced mainly by the lubricant types, [7, 13]. Deformation is accompanied by the relative movement between the tools and the work-part, where friction is

generated. Because friction controls the surface quality and sheet formability, it is necessary to apply the proper lubricant to reduce the drawbacks of increased friction. It was found that by the use of ring compression test, the dimensional variations of the test specimen could be used to determine the magnitude of friction coefficient, [14 - 17]. Friction was measured by sensors designed in metal working, [18 – 24]. Friction in rolling was measured during forming process. It was observed that friction coefficient of soft material slid on steel decreased depending on the applied normal load, [25]. Soft and brittle materials were found to be sensitive to the contact pressure. The possibilities to evaluate friction were discussed, [26 - 31]. Several friction models in cold metal process were explained.

In the present work, the effect of dispersing the lubricating grease by SiC nano-particles and MWCNT nano-tubes on friction coefficient and wear by bearing steel ball sliding on Al sheet simulating the frictional behavior during forming process is investigated.

EXPERIMENTAL WORK

Experiments were carried out to investigate the influence of the tested nano-materials dispersing lithium grease on friction coefficient and wear of the aluminium sheet that represented the aluminum tube when a bearing steel ball slid on it. The set-up test rig consists of a rigid stylus mount to produce a scratch on a flat surface with a single pass, using a hemispherical shape as shown in Figs. 1 and 2. The loading lever is connected to the stylus through three-jaw chuck. The balance of the loading lever before test was made using a counterweight. Weights of 2, 4, 6, 8 and 10 N are vertically applied. The load cell mounted on the loading lever and connected to the digital screen was used to measure horizontal scratch resistance force. Manual driving mechanism was used to move the specimen in a straight direction. The test was conducted under different lubricated conditions using lithium based grease dispersed by the tested nano-materials at the ambient temperature. The scratch width was measured by using an optical microscope with an accuracy of ± 1.0 μm.

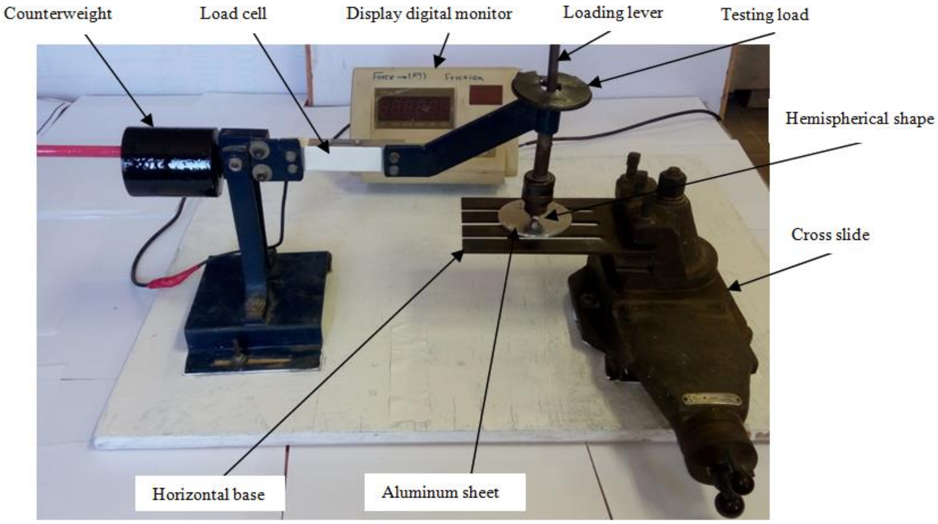

Fig. 1 Arrangement of the test rig.

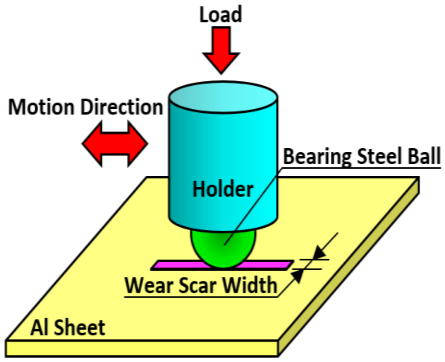

Fig. 2 Details of the friction test.

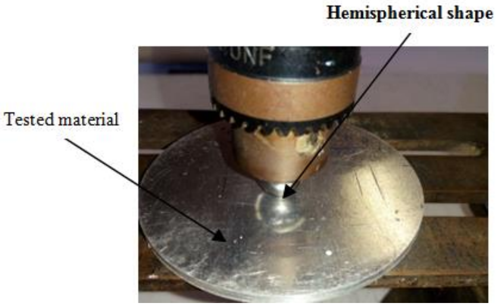

Fig. 3 photo of friction test.

RESULTS AND DISCUSSION

Finite element (FE) prediction of the load/displacement curves of the tube expansion process of commercial pure Al tube, was determined by an Elasto-plastic FE simulation, where the process was achieved by means of the computer program DEFORM 2D and 3D FE software version 11.0. The lower die/punch surfaces were assumed to be perfectly rigid. Frictional behavior between the inner tube diameter and expanding punch surfaces was assumed. Figure 3 shows the dependency of the exerted load on friction coefficient for different deformation values. It is clear that load slightly increased for the lower deformation and significantly increased for the higher deformation with increasing the values of friction coefficient. Besides, the figure illustrates that as the deformation increased the load increased.

Friction coefficient displayed by the grease dispersed by silica nano-particles, Fig. 4, slightly decreases down to the minimum value then slightly increased with increasing silica nano-particles content. The minimum values of friction coefficient were observed at 0.1 and 0.3 wt. % silica content. Further increase of the content of silica nano-particles increased wear due to the increased abrasiveness of the silica. They act as ball bearings rolling and separating the two contact surfaces, where metal to metal contact is prevented. They are environmentally friend and economic. The drawback is their crushing when the load is increased so that the rolling action is retarded, [32 - 38]. Besides, SiO_2 nanoparticles are more dispersive and stable than diamond nanoparticles in oil. The lubrication mechanism of the dispersion is shown in Fig. 5, where the rolling action is dominating.

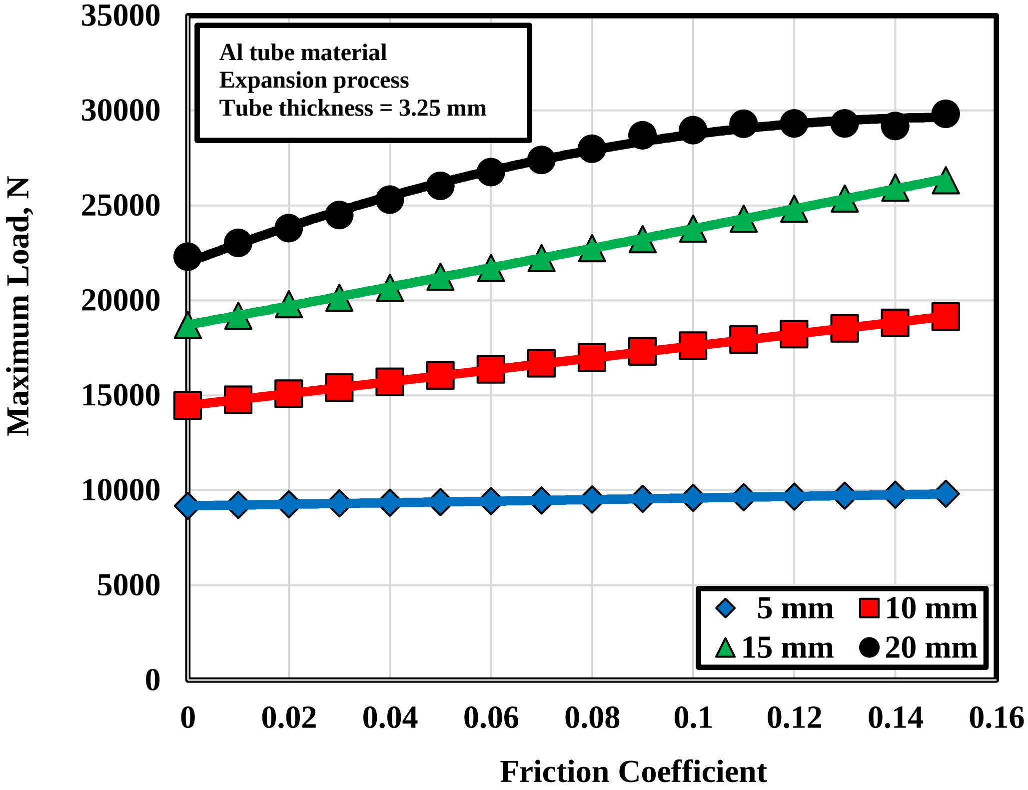

Fig. 3 Effect of friction coefficient on the simulated maximum forming load in the expansion process

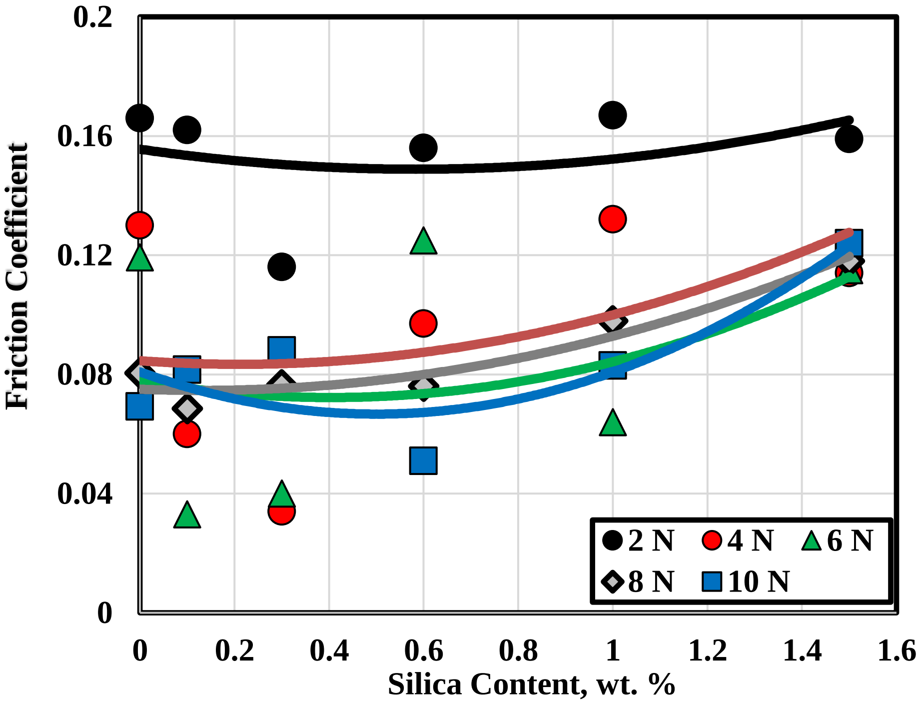

Fig. 4 Friction coefficient displayed by the grease dispersed by silica nanoparticles.

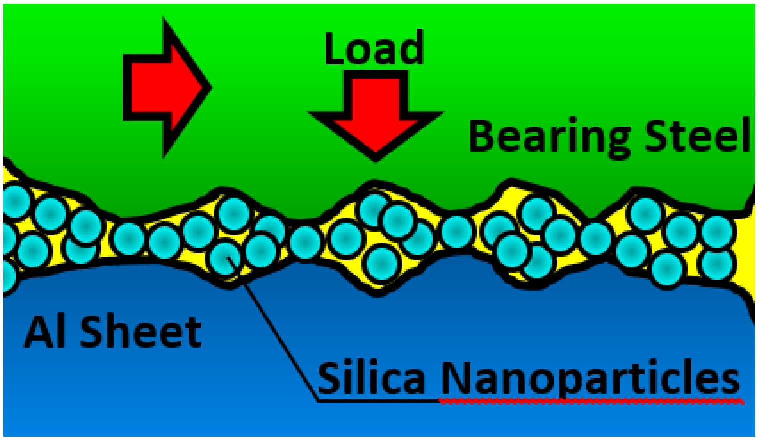

Fig. 5 Mechanism of action of silica nanoparticles.

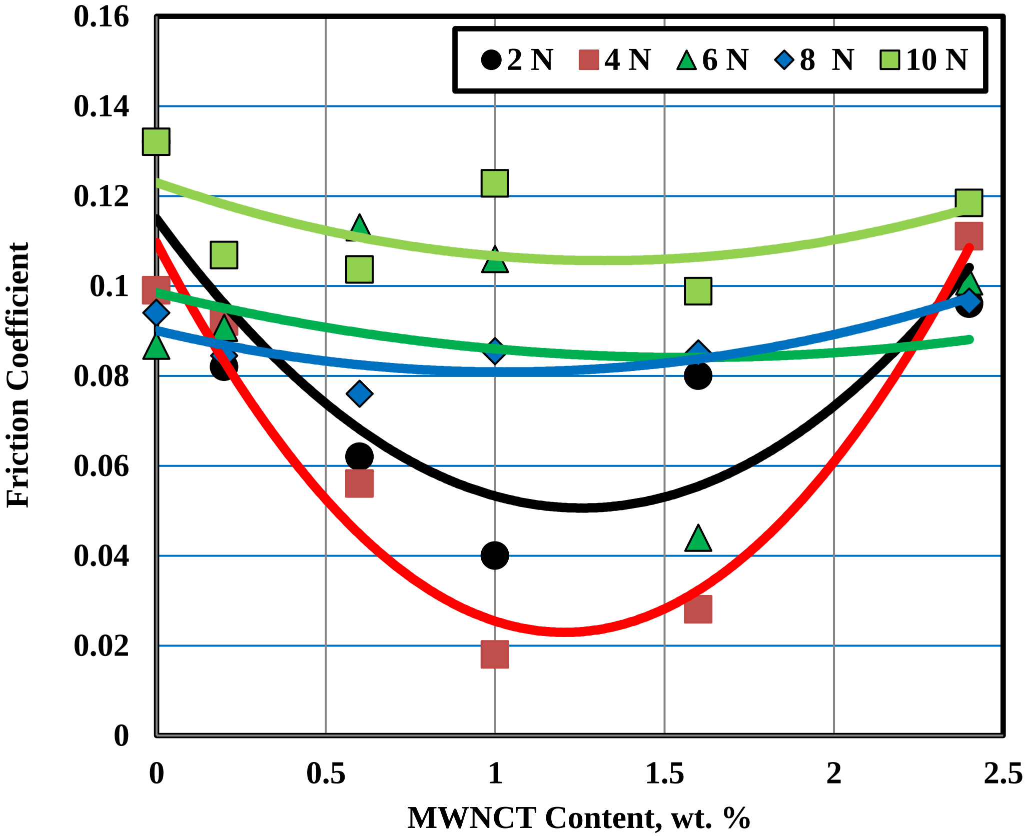

Fig. 6 Friction coefficient displayed by the grease dispersed by MWCNT.

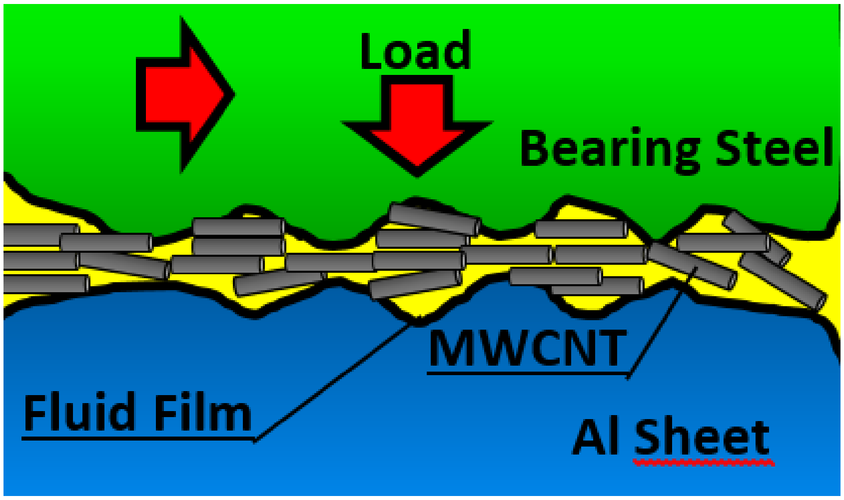

Fig. 7 Mechanism of action of MWCNT.

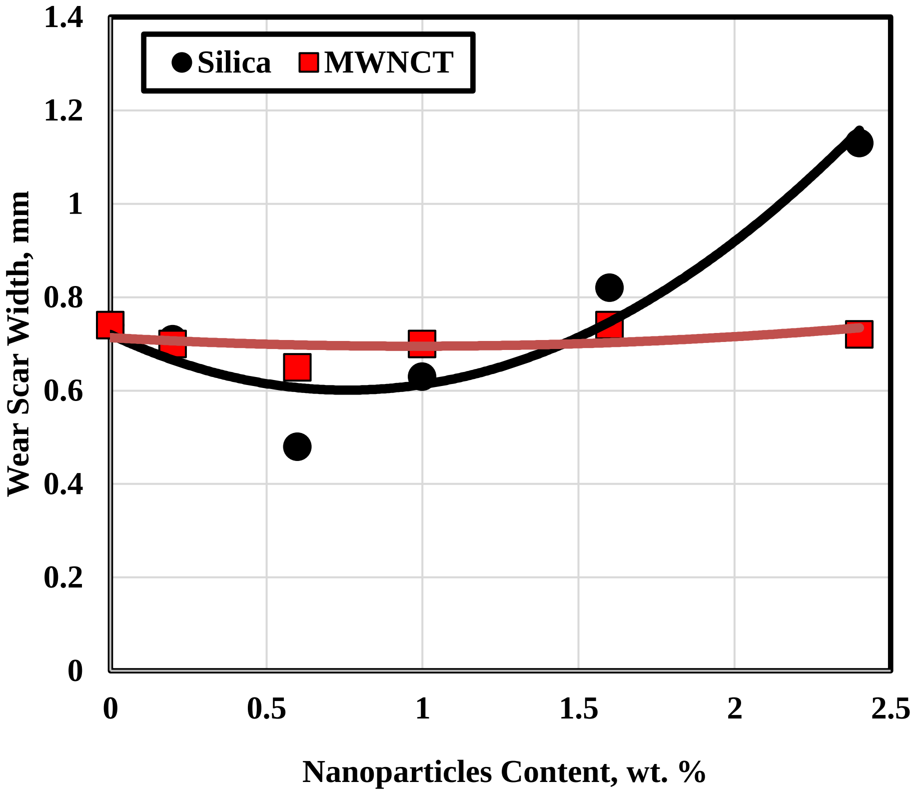

Fig. 8 Wear displayed by grease dispersed by nanoparticles.

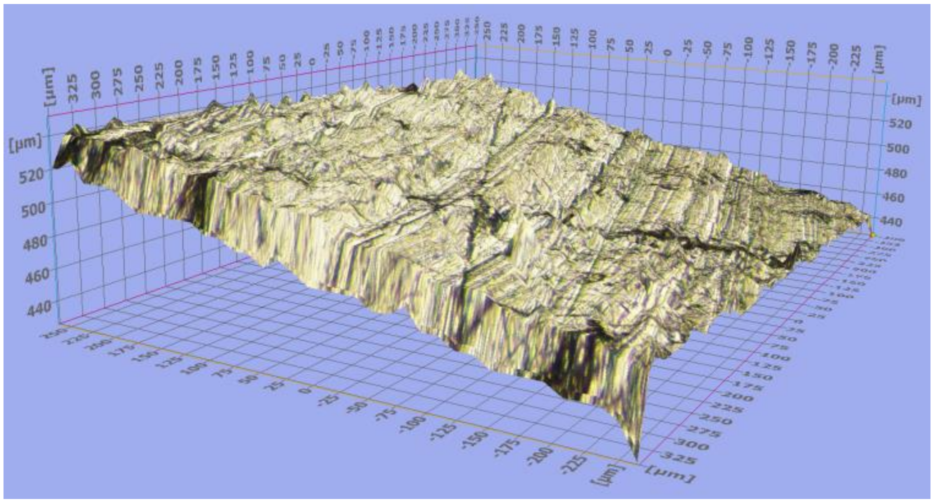

Fig. 9 Surface topography of test specimen lubricated by grease.

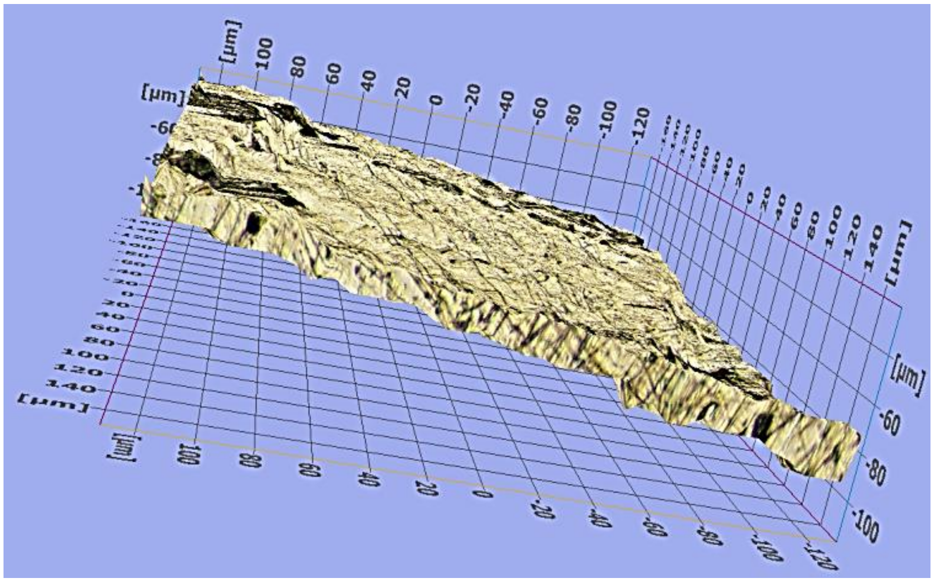

Fig. 10 Surface topography of test specimen lubricated by grease dispersed by 1.0 wt. % silica nanoparticles.

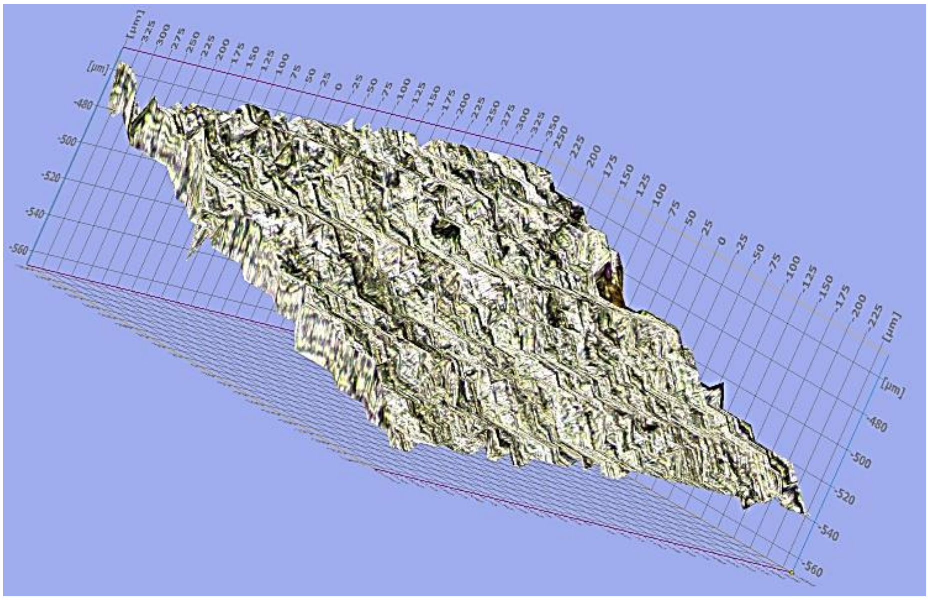

Fig. 11 Surface topography of test specimen lubricated by grease dispersed by MWCNT.

Friction coefficient displayed by the grease dispersed by MWCNT had the same trend observed for silica nanoparticles, Fig. 6, where minimum values were detected at 1.0 wt. % MWCNT content. Higher MWCNT content increased friction coefficient. It is clearly shown that MWCNT caused significant decrease in friction coefficient compared to oil free of additives and oil dispersed with silica nano-particles. This behavior might be attributed to the fact that MWCNT is quite good solid lubricant. The lubrication mechanism of MWCNT depends on their nature as cylinders. Their nano-size enables them to enter into and adsorbing on the asperities of the rubbing surfaces, Fig. 7. In this condition, friction is influenced by the rolling action of the nano-cylinders. It was proven that the carbon nature of MWCNT caused significant reduction in friction, where the carbon formed on the contact surface provided the surface by a low shear strength film that protected the rubbing surfaces from further friction and wear, Fig. 7. Wear of the test specimen measured by the wear scar width is shown in Fig. 8, where minimum wear was displayed by grease dispersed by 1.0 wt. % silica nanoparticles. Further increase in silica caused significant wear increase. MWCNT showed no influence on wear values.

The surface topography of the test specimen is shown in Figs. 9 – 11. Grease free of additives showed the roughest surface, Fig. 9. Longitudinal striations are shown with relatively deep valleys. Surface ridges are deformed due to the interaction of the asperities of the steel ball. The thickness of the test specimen was not uniform along the deformation direction. Surface topography of test specimen lubricated by grease dispersed by 1.0 wt. % silica nano-particles showed finer roughness and waviness, Fig. 10, due to the rolling action of silica particles. Test specimen lubricated by grease dispersed by MWCNT showed severely deformed surface, confirming that MWCNT

effect was insignificant, Fig. 11. The microscopic inspection confirmed the data shown by wear.

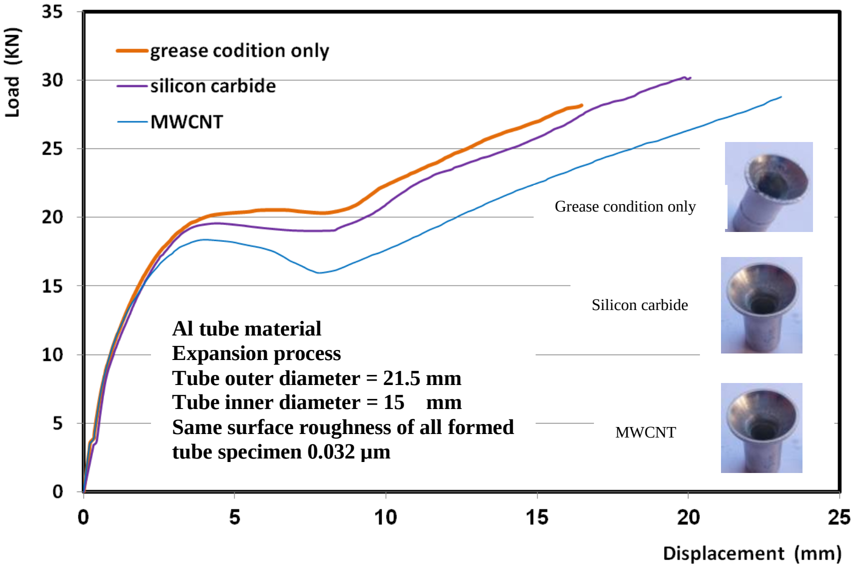

Fig. 12 Experimental load/displacement curves at different friction conditions.

Effect of different friction conditions of the load/displacement curve of tube expansion process with 30° semi-die of conical punch shape, 3.25 mm tube thickness, and aluminum tube material with grease free of additives, grease dispersed by 1.0 wt.% silica nano-particles and grease dispersed by 1.0 wt.% (MWCNT) carbon nano-tube were carried out as shown in Fig. 12. It is observed that, the values of the load/displacement curve with silica nano-particles and MWCNT additives were lower than that displayed by grease free of additives. In addition, the formability in the term of expansion ratio of the process increased by using these additives.

CONCLUSIONS

1. The load depends on the friction coefficient and the deformation.

2. Friction coefficient displayed by the grease dispersed by silica nano-particles slightly decreased down to minimum at the range of 0.1 and 0.3 wt. % content.

3. Friction coefficient displayed by the grease dispersed by MWCNT had the same trend with lower friction values.

4. Minimum wear observed for the test specimen was displayed by grease dispersed by 1.0 wt. % silica nano-particles. Further increase in silica caused significant wear increase. MWCNT showed no influence on wear values.

5. The surface topography with grease free of additives showed the roughest surface, while the test specimen lubricated by grease dispersed by 1.0 wt. % silica nano-particles showed finer roughness and waviness. Test specimen lubricated by grease dispersed by MWCNT showed severely deformed surface. The microscopic inspection confirmed the data shown by wear.

6. Silica nano-particles and MWCNT additives has great effect on the forming load and formability of the expansion process.

REFERENCES

1. Vilotić M., Kakaš D., Miletić A., Kovačević L., Terek P., “Influence of Friction Coefficient on Workpiece Roughness in Ring Upsetting Process”, 34th International Conference on Production Engineering, 28. - 30. September 2011, Niš, Serbia University of Niš, Faculty of Mechanical Engineering, (2011).

2. Lovell M. R., Deng Z., Characterization of interfacial friction in coated sheet steels: influence of stamping process parameters and wear mechanisms, Tribology International, Vol. 35, pp 85-95, (2001).

3. Sahin, M., Cetinarslan, C. S., Akata, H. E., “Effect of surface roughness on friction coefficients during upsetting processes for different materials”, Materials and Design, Vol. 28, pp. 633 - 640, (2007).

4. Behrens A., Schafstall H., “2D and 3D simulation of complex multistage forging processes by use of adaptive friction coefficient”, Journal of Materials Processing Technology, Vol. 80 - 81, pp. 298 - 303, (1998).

5. Schey J., “Metal Deformation Processes: Friction and Lubrication”, Marcel Dekker Inc., New York, (1972).

6. Alexandrov S., Vilotić D., Plančak M., “A New Approach for Determining the Friction Law in Metal Forming”, BALKANTRIB’O5 5th International Conference on Tribology June.15-18. Kragujevac, Serbia and Montenegro, (2005).

7. Makhkamov A., “Tribology in Sheet Metal Forming”, Porto, Portugal, July 2017 Department of Mechanical Engineering, Universidade Do Porto, Faculdade De Engenharia, (2017).

8. Kim H. and Kardes N., “Friction and Lubrication”, Sheet Met. Forming Fundamentals, ASM International, (2012).

9. Kirkhorn L., Bushlya V., Andersson M., and Stahl J. E., “The Influence of Tool Steel Microstructure on Friction in Sheet Metal Forming”, Wear, Vol. 302, No. 1 - 2, pp. 1268 - 1278, Apr. (2013).

10. Trzepieciński T., Bazan A. and Lemu H. G., “Frictional Characteristics of Steel Sheets Used in Automotive Industry”, Inter. Jour. of Auto. Tech., Vol. 16, No. 5, pp. 849 - 863, (2015).

11. Choi I. S., Joun M. S., Moon H. G., Lee M. C. and Jun B. Y., “Effects of Friction Laws on Metal Forming Processes”, Tribology International, Vol. 42, pp. 311–319, (2009).

12. Bay N., Olsson D. D. and Andreasen J. L., “Lubricant Test Methods for Sheet Metal Forming”, Tribol. Int., Vol. 41, No. 9 - 10, pp. 844 - 853, Sep. (2008).

13. Ceretti E., Fiorentino A., and Giardini C., “Process Parameters Influence on Friction Coefficient in Sheet Forming Operations”, Ind. Eng., pp. 2–5, (2008).

14. Rajesh E. and Prakash M. S., “Analysis of friction factor by employing the ring compression test under different lubricants”, International Journal of Scientific & Engineering Research, Volume 4, Issue 5, pp. 1163 – 1171, (2013).

15. Thakur R., Gangwar M., Jain P., “Development of New Design of Specimens for Friction Determination in Metal Forming”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 3, Issue 5, pp. 21 - 26, (2012).

16. Chan H., “Determination of friction models for metallic die work piece interfaces”, International Journal of Mechanical Sciences, Vol. 47, pp. 1-25, (2005).

17. Hasan S., Rasty J., "Determination of friction coefficient utilizing the ring compression test", Journal of Engineering Materials and Technology, pp. 338 - 348, (2001).
18. Jeswiet J., Arentoft M., and Henningsen P., "Methods and Devices Used to Measure Friction in Rolling", IMechE Proc. IMechE Vol. 220 Part B: J. Engineering Manufacture, pp. 49 – 57, (2006).
19. Jeswiet J. and Wild P., "Sensing Friction: Methods and Devices", J. Forming Processes, 4(2), pp. 125 - 134, (2001).
20. Dellah A., Wild P. M., Moore T. N., Shalaby M., and Jeswiet J., "An Embedded Friction Sensor Based on a Strain Gauged Diaphragm. J. Mfg Sci. Engng, 124, pp. 523 - 527, (2002).
21. Yajure E., MSc Thesis, Queen's University, Kingston, Ontario, Canada, (2002).
22. Henningsen P., Arentoft M., and Wanheim W., "Measurements of Normal and Friction Forces in a Rolling Process", In Proceedings of the Second International Conference on Tribology in manufacturing processes (ICTMP), (2004).
23. Miavaghi A. S., Kangarlou H., Eskandarzade M., "Comparison Between Frictional Behavior of the Soft and Brittle Materials at Different Contact Pressures", Lebanese Science Journal, Vol. 18, No. 1, pp. 98 – 105, (2017).
24. Jiménez M. A., Bielsa J. M., Rodríguez R. and Dobón S., "The Influence of Contact Pressure on the Dynamic Friction Coefficient in Cylindrical Rubber-Metal Contact Geometries", IUTAM Symposium on Computational Methods in Contact Mechanics, (2007). Proceedings of the IUTAM Symposium held in Hannover, Germany, November 5 - 8, P. Wriggers and U. Nackenhorst. Dordrecht, Springer Netherlands. 257-275, (2006).
25. Keum Y. T., Wagoner R. H. and Lee J. K., "Friction Model for FEM Simulation of Sheet Metal Forming Operations", AIP Conference Proceedings, 712, (1), pp. 989 - 994, (2012).
26. Plančak M., Car Z., Kršulja M., Vilotić D., Kačmarčik I., Movrin D., "Possibilities to Measure Contact Friction in Bulk Metal Forming", Tehnički vjesnik 19, 4, pp. 727-734, (2012).
27. Plančak M., Barisić B., Vilotić D., "Kačmarčik I., Movrin, D., Skakun P., Milutinović M., "Analytical and Numerical Solutions for Friction Calibration Curves (FCC) in Bulk Metal Forming", CA systems in production planning, 12, 1, pp. 107-112, (2011).
28. Plančak M., Vilotić D., Stefanović M.; Kačmarčik I., Movrin D., "A Contribution to the Modelling of Ring Compression Test for Determination of Friction in Bulk Metal Forming Processes", Balkan Trib, Thessaloniki, (2011).
29. Fereshteh-Saniee F., Pillinger I., Hartley P., "Friction Modelling for the Physical Simulation of the Bulk Metal Forming Processes", Journal of Material Processing Technology", pp. 153 - 154, pp. 151-156, (2004).
31. Vilotić D., Plančak M., Kuzman K., Milutinović M., Movrin D., Skakun P., Lužanin O., "Application of Net Shape and Near-Net Shape Forming Technologies in Manufacture of Roller Bearing Components and Cardan Shafts", Journal for Technology of Plasticity, 32, pp. 87 – 103, (2007).

32. Peng D. X., Kang Y., Hwang R. M., Shyr S. S., Chang Y. P., "Tribological properties of diamond and SiO_2 nanoparticles added in paraffin. Tribology international, 42, pp. 911 - 17, (2009).
33. Choi Y., Lee C., Hwang Y., Park M., Lee J., Choi C., et al., "Tribological behavior of copper nanoparticles as additives in oil", Curr. Appl. Phys., 9, pp. 124 - 127, (2009).
34. Peng D. X., "Tribological properties of diamond and SiO_2 nanoparticle added in paraffin", (42), Tribology International, pp. 911 - 917, (2009).
35. He Q., "Effect of nanometer SiO_2 on the frictional behavior of lubricating grease", Journal of sagepub.com (7), pp. 1 - 9, (2017).
36. Peng D. X., "Size effect of SiO_2 nanoparticle as oil additives on tribology of lubricant", Industrial Lubrication and Tribology, (62), pp. 111- 120, (2018).
37. Jio D., "The tribology properties of alumina/silica composite nanoparticle as lubricant additives", Appl. Surf. Sci., 257 (13), pp. 5720 - 5725, (2011).
38. Lopez T. D., "Engineered silica nanoparticle as additives in lubricant oils", (16), Sci. Technol. Adv. Material, (16), pp. 23 – 34, (2015).