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Review Article

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Experimental Methods of Friction Evaluation in Bulk Metal Forming Processes - An Overview

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Abstract

In different manufacturing sectors, specifically in metal forming processes, friction plays a vital role in achieving better quality products, maintaining good die life and consuming lesser energy etcetera. Friction in metal forming process depends on various factors like relative velocity, local temperature, contact pressure, contact surface topography, surface contaminations, oxidations and so on. The friction phenomenon is widely investigated since the eighteenth century; still, there areno established techniques to evaluate it by addressing all the factors. For quantitative estimation of load in forming industries through numerical and analytical solutions, the constant shear friction model has been widely utilized. This review article summarizes some of the widely used techniques to evaluate tool-workpiece interface friction. Ring compression test, uniaxial cylinder compression test, T-shape compression test, the combination of extrusion friction test, and double-backward extrusion test methodologies are discussed here. The initial two methodologies suit low deformation condition processes whereas others arepreferred for techniques inducing huge deformation.

Keywords

Friction testing methodology, Ring compression test, T-shape compression test, Extrusion friction test

Introduction

Almost in every metal forming process, high-pressure sliding between the work material and tool takes place. The resistance for the relative motion under a normal load is recognized as friction, which plays a vital role and is mostly unfavorable in nature [1]. Friction influences the process in many ways like material flow characteristics, surface layer deformation of both tool and workpiece, net energy required to accomplish the process, heat generation, tool life, etc. [2]. Many research works were conducted to minimize the adverse effects of friction by utilizing and improvising the performance of lubrication. At the same time, the effect of variable parameters that influence friction was closely monitored and controlled incisively for its lesser impact [3]. Friction depends on many factors like contact pressure, interface temperature, surface roughness [4], surface contaminations, relative sliding velocity, etc., hence, is not an independent entity so cannot be measured directly [5]. Various methodologies had been suggested by several researchers to study, estimate, and evaluate the frictional conditions. Some of the widely used techniques for evaluating friction conditions are upset test, ring-compression test, T-shape compression test, double- cup extrusion test and the rest.

The frictional force is a tangential one and occurs at the contact interface between two bodies which always oppose the relative motion. The maximum frictional force that is exerted on one body by another at the interface depends on many factors such as thermo-mechanical behaviour, chemical behaviour, contact surface characteristics and applied load etc. The dependable of friction [6] are represented in a fishbone diagram in figure 1. The factors presented in the diagram are more prominent for the micro forming operations.

The phenomenon of friction is of great importance in metal forming operations because of several reasons. It influences the maximum load hence total energy consumption, subsurface deformation hence surface quality, wear of the dies and die life as well, etc. Though it is an entrapping phenomenon and not openly visible, complete understanding and evaluating friction is very difficult. Different models have been proposed by different researchers to estimate and analyze the process. Bowden and Tabor proposed a theory known as adhesive theory of friction which emphasizes the real contact area between two contact surfaces. At high pressures, the contact asperities deform and form the adhesive bonding with the counter contact point. The tangential force required to brake/shear off the bonds is considered as friction force [7]. Amontons [8] conducted many experiments to observe the behavior of friction and concluded with three laws on dry friction. As per the claim, frictional stress is independent of contact area and sliding velocity, but it directly depends on contact pressure and surface irregularity. The investigation was further developed by Charles-Augustin de Coulomb. Coulomb [9] proposed the model between two sliding contact bodies and it remained most suitable under low contact pressure conditions. The model is appropriate where the mean contact pressure (σ_n) is less than the flow stress (σ_0) of the softer body. In different metal forming operations such as extrusion, closed die forging, etc., where $\sigma_n >> \sigma_0$ the model overestimates the friction value. For such cases, a constant shear stress friction model was proposed and known as the Tresca friction model [10]. The model remained popular due to its simplicity, but it fails to perform at low contact pressure conditions. Wanheim and Bay [11, 12] proposed a rounded transition between both Coulomb and Tresca's friction model. This non-linear refined model describes the friction conditions more incisively than either of the two aforesaid models. The comparative diagram of different friction models is presented in figure 2a. The impact of normal pressure on the variation of apparent and actual contact area at higher loading conditions is evident in figure 2b and 2c.

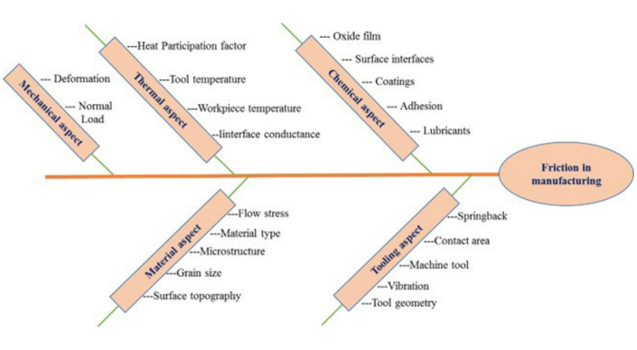


Figure 1: Dependables of friction in micro forming [8].

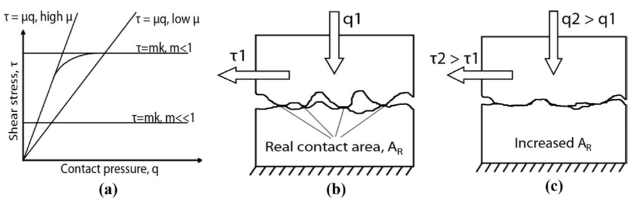


Figure 2: **(a)** Different friction models, **(b)** adhesion friction model for low pressure, and **(c)** model for high normal pressure [13].

The selection of the friction model in metal forming analysis takes a fundamental role and affects the agreement of the physical behavior with the numerical modelling. Though the relative sliding between the tool and workpiece takes place under high contact pressure and maybe at high temperatures, it is very difficult to quantify friction. In this review article different existing friction testing techniques, those commonly utilized for estimating a constant friction value in the metal forming industries are discussed.

Ring Compression Test

In 1956, Kunogi introduced the ring compression test, which is the most commonly used method for determining friction in metal forming industries [13]. In 1963, the process was further developed by Male and Cockcroft [14] for the effective and efficient evaluation of constant friction shear factor '*m*' or coefficient of friction 'μ'. For the test, a flat ring (specimen) is to be compressed axially between two flat parallel tool plates. The variation of the inner diameter of the ring after compression depends on the friction value. Usually, the dimension proportions of the ring follow OD0:ID0:H0 = 6:3:4 or 6:3:2 or 6:3:1. At zero friction conditions or very low friction conditions, the material flows outward radially as if it were a solid element and both inside and outside diameter of the ring increases. When the value of friction exceeds a critical one, the material near the inner periphery flows inwards and the material near the outer periphery flows outward. Both contraction and enlargement of diameters take place. The schematic presentation for low friction or good lubrication condition and poor lubrication condition is presented in figure 3. Considering the value of 'm' or 'μ' constant over the interface and homogeneous deformation or zero barreling effect, some analytical works were carried out. Based on the analytical equations the relationship between axial reduction of the height and change of inside diameter was established. The theoretical curves for the variation of internal diameter with height reduction at different friction values are presented in figure 4. This kind of friction calibration curve (FCC) can be utilized to relate the experimental results to quantify the friction value approximately, by ring compression test. The value of m = 1 (μ = 0.577) is of course a sticking friction condition where there is no relative sliding between interfaces and m = μ = 0 is no friction condition. Much experimental research works along with finite element analysis were conducted to extract new conclusions on the ring compression test [13, 15, 16].

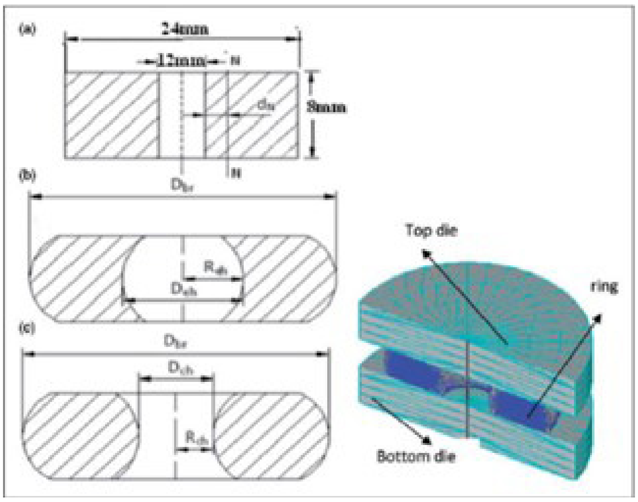


Figure 3: Ring geometry **(a)** before upsetting, **(b)** after upsetting-good lubrication, and **(c)** after upsetting poor lubrication [28].

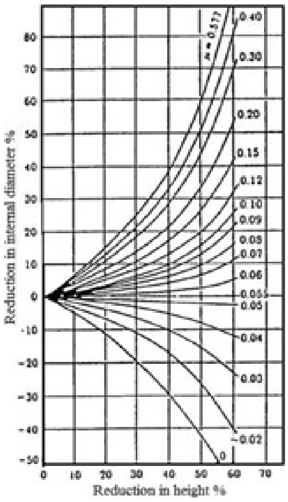


Figure 4: Typical friction calibration curves for the evaluation of friction factors [20].

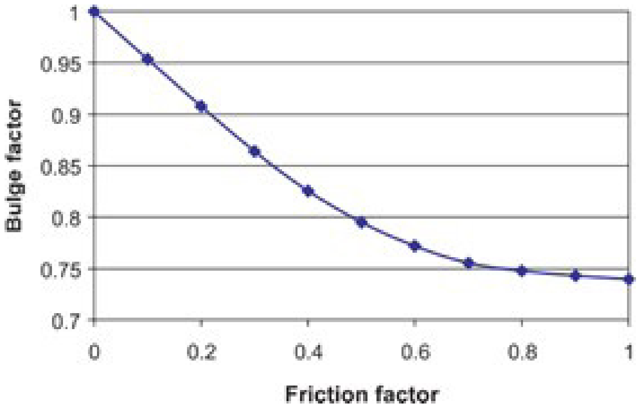


Figure 5: Bulge factor vs Friction factor for h/d = 1.5.

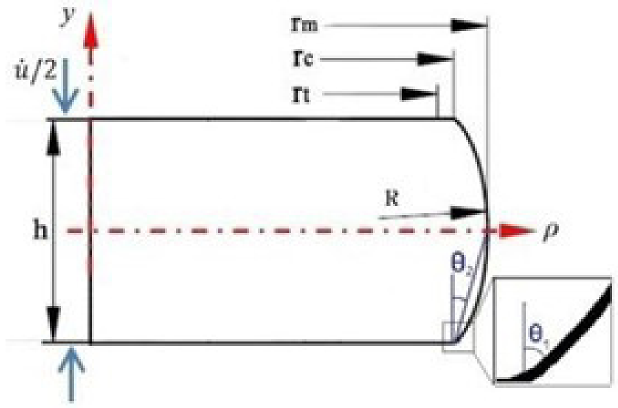


Figure 6: Deformed cylinder geometry [29].

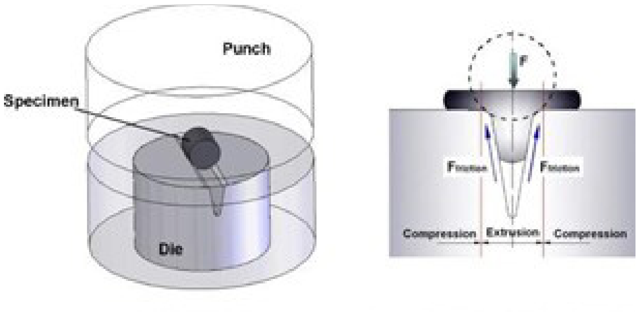
To study the deformation behavior, numerical simulations were conducted by researchers considering a few major variables like different friction and lubrication conditions, compression rate, operating temperatures, etc. It was observed that the effect of temperature on interface friction and load stroke behaviour is more prominent than other variables. However frictional changes minutely hamper the load stroke behaviour.

Uniaxial Cylinder Compression Test

Uniaxial compression of a cylindrical specimen is the simplest and most practical technique to investigate the thermo-mechanical behaviour and microstructural evolution in plastic deformation processes [17, 18]. A constant friction factor at tool-workpiece interface can be quantified from the non-uniform deformation i.e., bulging effect of the specimen [19]. After thorough experimentation, many researchers claimed that the bulge profile is friction sensitive. The slope of the bulge profile at the contact interface is the most sensitive which could be a better estimator of friction. A bulge parameter, (ratio of diameter at top or bottom to the maximum diameter at the center after compression) was set for a specimen of aspect ratio (h/d) 1.5 at fixed operating conditions of the experiment. The parameter was plotted with friction values and set as a calibration curve by Sivaprasad et al. [20] as presented in figure 5. Different geometrical parameters such as rm, rc [21], rt as shown in figure 6 were mostly utilized for the calibration and estimation of friction. Different calibration curves have been plotted by many researchers considering different geometrical variables with different methods.

T-Shape Compression Test

After the compression, the cross-section of the cylindrical specimen changes to ‘T- shape’, hence named as T-shape compression test [22]. A punch and a V-grooved die setup are required for compressing the cylindrical billet. The isometric line diagram of the setup and the front cross-sectional line diagram of the billet after compression (partially upset and partially extrudate) are presented in figure 7. Two distinct metal flows are extrusion at the groove and compression along the flat face. Both positive and negative principal strains are induced during the operation. The friction force at the wall of the groove as presented in figure 7b in an upward incline arrow opposes the extrusion and the height of the extrusion is influenced by frictional opposition. Both forming load and shape of the specimen after forming are very much friction



(a) Set-up of test (b) Deformation characteristic of specimen

Figure 7: (a) isometric line diagram of the setup and **(b)** front cross- sectional line diagram of the billet after compression [24].

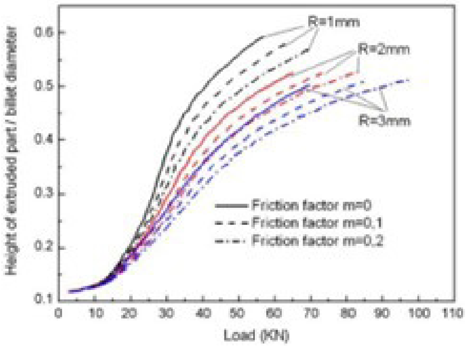


Figure 8: h/d vs load at different friction conditions and different corner radius [24].

sensitive. Calibration curves by considering the ratio of the height of extrudate to the original diameter of billet and load are plotted by Fereshteh-Saniee et al. [23] at different strain rates and at different temperatures. A similar kind of finite element analysis was conducted by Zhang et al. [24] and the calibration curve for different die corner radius is presented in figure 8. At the decreased corner radius, it was observed the slope of load-stroke curve decreased and the height of the extruded part increased. Hence smaller corner radius die was suggested for the test [24]. However, a decrease in friction sensitivity and an increase in the slope of the load curve occur with the increase in die V-groove angle. Therefore, a smaller V-groove angled die is always suggested for the test. This simplified process has a lot of scope to investigate more and to form several calibration curves for its better establishment.

Double Cup Extrusion Test

In industrial metal forming operations, where deformation is severe, the contact pressure is very high, material flow conditions are drastic, ring compression tests and uniaxial cylinder compression tests fail to reflect the real picture of boundary deformation as well as friction [25]. Again, the deviation is severe in the micro-manufacturing process. To estimate and evaluate friction, at huge deformation conditions, some new methods have been developed in the previous few decades. In the 1990s, extrusion friction tests were proposed and thereafter, few modifications were done with the die setups. A few tests like the double cup extrusion (DCE) test, strip drawing test, upsetting sliding test, T-shape compression test, and injection-upsetting were predominantly used for evaluating friction. Figure 9 shows different friction tests belonging to the extrusion group. To get better friction sensitivity flow, researchers tailored the existing extrusion die setup minutely and experimented. In the case of DCE, movement is provided to only upper punch while the bottom punch and die remain stationary. Hence the flow of metals remains different at respective zones which reflects the sensitivity of frictional effect. The ratio of cup heights H_1/H_2 (H_1 = upper cup height, H_2 = lower cup height) vary at different friction conditions. Through simulations in DEFORM-2D the expression at different friction conditions were plotted against stroke at different friction conditions by Molaei et al. [26]. In the research, they also established the relationship between constant friction factor (m) and coefficient of friction (μ). forward conical/straight can–backward straight can extrusion [25].

In the case of combined forward and backward extrusion process shown in figure 10, at the backward side a can is produced and at forwarding side, a rod is produced [25]. The lengths of forward and backward extrudates are friction sensitive. The ratios of lengths determine the friction factor. At higher friction conditions the length of extrudate will be smaller compared to low friction conditions. Considering different designs of dies, at different friction and temperature conditions, several finite element simulations were conducted by different researchers. From the results considering the length of the extrudate, calibration curves are set to evaluate the

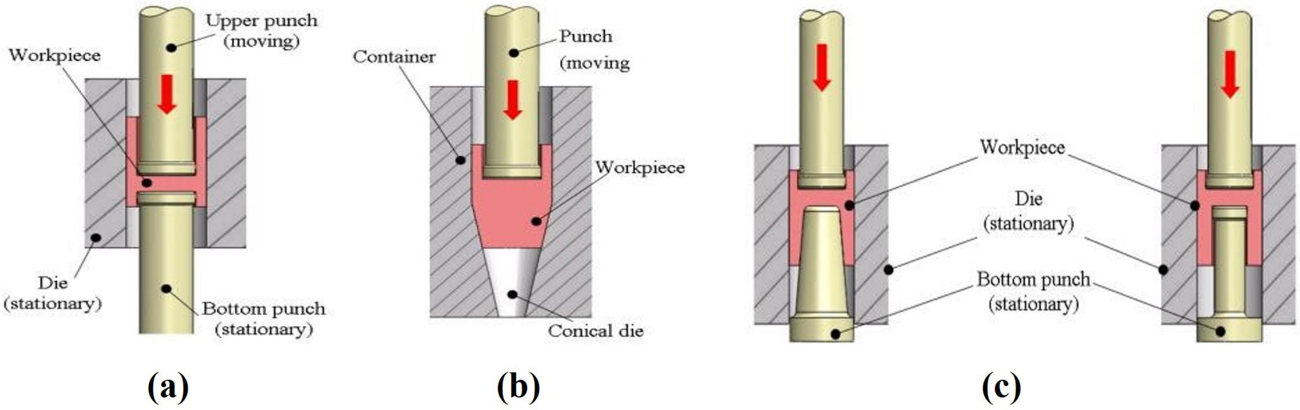


Figure 9: The design of **(a)** double cup backward extrusion, **(b)** combined forward rod-backward can extrusion, and **(c)** combinedforward conical/straight can–backward straight can extrusion [25].

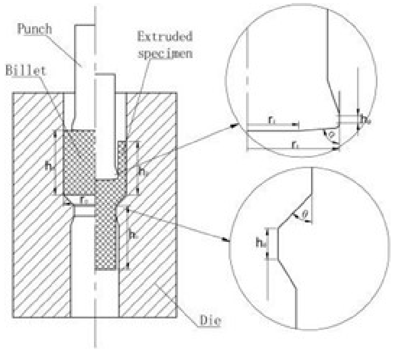


Figure 10: Schematic cross-sectional initial and final layout of combined forward and backward extrusion [8].

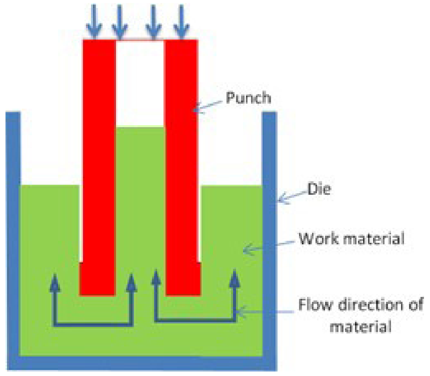


Figure 11: Schematic cross-sectional view of double-backward extrusion method.

experimental friction value [27]. Different process parameters like extrusion ratio, extrusion velocity, corner radius of the punch, temperature, and surface roughness of the die setup can be utilized /altered for better investigation.

Double-Backward Extrusion Test

A new method, proposed by Kang et al. [27] where a cylindrical billet is backward extruded by a punch having a central hole. Billet material flows in two directions as shown in figure 11. The material flow at the central zone is friction dependent. At high friction conditions, a greater amount of material flows through the central hole in punch. The height of the central zone of the specimen after deformation may be calibrated for friction estimation. For determining friction coefficient FCCs need to be obtained by different finite element simulations. Very few works were reported on this test methodology, hence the scope is there for further investigation.

Summary

Friction is a phenomenon that needed to be investigated and understood very crucially because of its unfavorable role in most of the metal-forming operations. Energy consumption, die life, product quality etc. are directly influenced by the phenomenon. Even for analytical, numerical and simulation work, the knowledge of friction is quite essential. For the quantification of friction value in metal forming process, several methods were invented and investigated. Out of the many methods, some of the most utilized methods like, the ring compression test, uniaxial cylinder compression test, T-shape compression test, double cup extrusion test and double-backward extrusion test were discussed in this article. For lower deformation conditions ring compression and uniaxial cylindrical compression test remain suitable but for severe deformation conditions, other tests give better estimation and real comparisons. Still, the real estimation and real picturization of friction are not understood properly. None of the tests can study theeffect of surface chemistry and oxide films at the interface. A lot of scope to research and reveal the real phenomenon as well as to explore newly introduced methodologies.

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Conflict of Interest

The Authors declare no competing interests that are relevant to the content of this article.

Credit Author Statement

Sambit Kumar Mohapatra: Conceptualization, Methodology, Resources, Supervision; Vikas Ranjan: Writing - review and editing; Rahul: Resources; Pushkar Jha: Formal analysis, Investigation; Asit Behera: Writing - original draft preparation; Kamal Kishore Joshi: Writing - original draft preparation. All the authors read and approved the manuscript.

References

1. Cristino VAM, Rosa PAR, Martins PAF. 2015. The role of interfaces in the evaluation of friction by ring compression testing. Exp Tech 39: 47-56. https://doi.org/10.1111/j.1747-1567.2012.00857.x
2. Mishra B, Mohapatra SK, Ranjan V, Maity K. 2020. Equal channel angular pressing of the aluminium alloy: a numerical investigation. Mater Today Proc 26: 2173-2178. https://doi.org/10.1016/j.matpr.2020.02.474
3. Mohapatra SK, Maity KP. 2016. Parametric optimization of simulated extrusion of square to square section through linear converging die. IOP Conf Ser Mater Sci Eng 115(1): 012031. https://doi.org/10.1088/1757-899X/115/1/012031
4. Koura MM, Omar MA. 1981. The effect of surface parameters on friction. Wear 73(2): 235-246. https://doi.org/10.1016/0043-1648(81)90293-3
5. Suh NP, Mosleh M, Howard PS. 1994. Control of friction. Wear 175(1-2): 151-158. https://doi.org/10.1016/0043-1648(94)90178-3
6. Dixit US, Yadav V, Narayanan GR, Bhardwaj N. 2018. Friction in micromanufacturing. J Micromanuf 1(1): 76-91. https://doi.org/10.1177/2516598418766918
7. Bowden FP, Tabor D. 2001. The Friction and Lubrication of Solids. Oxford University Press.
8. Amontons G. 1999. De la Resistance Cause'e dans les Machines (2). J Japanese Soc Tribol 44: 236-241.
9. Coulomb CA. 1821. Théorie des Machines Simples en Ayant égard au Frottement de Leurs Parties et à la Roideur des Cordages. Bachelier.
10. Schey JA. 1970. Metal Deformation Processes: Friction and Lubrication.

11. Widerøe F, Welo T. 2012. Conditions for sticking friction between aluminium alloy AA6060 and tool steel in hot forming. Key Eng Mater 491: 121-128. https://doi.org/10.4028/www.scientific.net/KEM.491.121
12. Wanheim T, Bay N. 1978. A model for friction in metal forming processes. CIRP Annals 27: 189-194.
13. Gomez D, Ledesma E, Hino R, Hamasaki H, Aguilera E, et al. 2021. Friction assessment in hot forging operations using large-scale ring compression test. ASME Int Mech Eng Cong Exp 85550: V02AT02A054. https://doi.org/10.1115/IMECE2021-71851
14. Male A. 1964. A method for the determination of the coefficient of friction of metals under conditions of bulk plastic deformation. J Inst Met 93: 38.
15. Harikrishna C, Davidson MJ, Raju SP, Rao GS. 2018. Utilization of ring compression test to investigate the mushroom effect and adhesive nature of AA2014 billets. Adv Mater Res 1148: 96-102. https://doi.org/10.4028/www.scientific.net/AMR.1148.96
16. HariKrishna CH, Davidson MJ, Nagaraju CH, Kumar AB. 2016. Effect of lubrication on hardness in the ring compression test. Proc Inst Mech Eng Part C J Mech Eng Sci 230(12): 1939-1950. https://doi.org/10.1177/0954406215586590
17. Ebrahimi R, Najafizadeh A. 2004. A new method for evaluation of friction in bulk metal forming. J Mater Process Technol 152(2): 136-143. https://doi.org/10.1016/j.jmatprotec.2004.03.029
18. Shin KH, Lee YS, Kim HS. 2014. The flow behavior modeling of AZ61 magnesium alloy at elevated temperatures considering the effects of strain rate and grain size. Int J Precis Eng Manuf 15: 745-751. https://doi.org/10.1007/s12541-014-0395-9
19. Sivaprasad PV, Davies CHJ. 2005. An assessment of the interface friction factor using the geometry of upset specimens. Model Sim Mater Sci Eng 13(3): 355. https://doi.org/10.1088/0965-0393/13/3/005
20. Fan XG, Dong YD, Yang H, Gao PF, Zhan M. 2017. Friction assessment in uniaxial compression test: a new evaluation method based on local bulge profile. J Mater Process Technol 243: 282-290. https://doi.org/10.1016/j.jmatprotec.2016.12.023
21. Ben NY, Zhang Q, Bandyopadhyay K, Lee MG. 2020. Analysis of friction behaviour under oscillating forming process using T-shape compression test and finite element simulation. J Mater Process Technol 275: 116327. https://doi.org/10.1016/j.jmatprotec.2019.116327
22. Fereshteh-Saniee F, Fallah-Nejad K, Beheshtiha AS, Badnava H. 2013. Investigation of tension and compression behavior of AZ80 magnesium alloy. Mater Des 50: 702-712. https://doi.org/10.1016/j.matdes.2013.03.080
23. Molaei SH, Shahbaz M, Ebrahimi R. 2014. The relationship between constant friction factor and coefficient of friction in metal forming using finite element analysis. Iranian J Mater Form 1(2): 14-22.
24. Wang L, Zhou J, Duszczyk J, Katgerman L. 2012. Friction in aluminium extrusion-part 1: a review of friction testing techniques for aluminium extrusion. Tribol Int 56: 89-98. https://doi.org/10.1016/j.triboint.2012.01.012
25. Hu C, Yin Q, Zhao Z. 2017. A novel method for determining friction in cold forging of complex parts using a steady combined forward and backward extrusion test. J Mater Process Technol 249: 57-66. https://doi.org/10.1016/j.jmatprotec.2017.06.001
26. Kang SH, Yun YW, Lee YS. 2009. Proposal of Novel Friction Testing Method in Bulk Metal Forming. In Proceedings of the Korean Society for Technology of Plasticity Conference, The Korean Society for Technology of Plasticity.
27. Plančak M, Car Z, Kršulja M, Vilotić D, Kačmarčik I. 2012. Possibilities to measure contact friction in bulk metal forming. Tech Gazette 19(4): 727-734.
28. Mittelman B, Priel E, Navi NU. 2018. A finite element study of thermo-mechanical fields and their relation to friction conditions in Al1050 ring compression tests. J Manuf Mater Process 2(4): 83. https://doi.org/10.3390/jmmp2040083
29. Zhang Q, Felder E, Bruschi S. 2009. Evaluation of friction condition in cold forging by using T-shape compression test. J Mater Process Technol 209(17): 5720-5729. https://doi.org/10.1016/j.jmatprotec.2009.06.002