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# Characterization of Ti64 forging friction factor using ceramic coatings and different contact conditions

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**Abstract**

Hot forging processes are highly influenced by the contact conditions between the billet and the dies. A wrong definition of the contact conditions may lead to wrong predictions of the final component geometry, the quantity of material necessary to fill in the cavity, the wear of the tools and the force necessary to manufacture the component.

Furthermore, when dealing with titanium alloys, the alpha case formation due to oxidation is critical. For that reason, ceramic coatings are used to prevent billet oxidation during the heating stage and to improve the material flow lowering the friction coefficient between the billet material and tooling.

In the present study, Ring Compression tests and T-Shape tests are carried out using ceramic-coated samples and friction behavior of Ti64 in contact with heated tool steel is studied. The final aim of the study has been to analyze the same tribo-system but having different contact pressures, sliding velocities and surface enlargement factors, which could affect the coating behavior.
As a result, the friction coefficients are calculated for the above-mentioned tribo-tests by the comparison of the experimental data and numerical simulation results.



*Keywords:* Ring compression test, T-Shape test, Titanium

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## 1. Introduction

In hot forging, interface heat transfer and friction effects are of particular importance since a hot work-piece is deformed using tooling whose initial temperature is often considerably lower. The heat transfer has significant effect due to the fact that non-uniform temperature distribution in the work-piece has a significant effect on process factors such as; forging forces, lubricant performance, die deflection and microstructure and consequently on the quality of hot formed parts. Therefore, it is important to be able to predict and if possible to control temperature fields arising during hot metal forming processes [1-3].

At the same time, friction between the forming tools and the work-piece has a significant effect on material flow, forming forces, component surface finish and die wear. Several methods have been developed for quantitative evaluation of interface friction such as clamp rolling, double cup extrusion test, ring-compression, etc. Among them, the ring-compression test is a widely accepted way to measure the interface friction between the work pieces and dies due to its simplicity [4-5]. By using the ring compression test, Li et al. studied the lubricities of glass and graphite in deformation process of Ti–6Al–4V titanium alloy under high temperatures and strain rates, and presented that increasing the strain rate leads the friction to reduce [6-7]. Zhu et al. determined the shear friction coefficient of the titanium alloy Ti-6Al-4V in the hot forging process by means of the ring compression test using a physical experiment and FE simulation [8]. Lastly, in 2015, Mirahmadi et al. studied the hot forging of Ti64 rings using glass coatings and concluded that deformation rate had a significant effect on the friction factor at 850 and 950°C, but its effect was inconsiderable at 900°C [9].

However, this test introduces small new surface expansion ratio, which nearly equals to 20% and very simple deformation path and many researchers have developed new tests to solve these problems. Double cup (combined forward and backward cup) extrusion was initially explored by Geiger [10] and using this test Barcellona et al. [11] concluded that this test is more appropriate for predictions in extrusion and closed-die forging operations in comparison to the ring test. Schrader et al. [12] found that the estimated friction factor by this method is relatively small since the contact pressure on the interface is smaller than that of the real forging process. Petty [13] proposed the spike test for estimating friction in hot metal forging. By using spike forging process and finite element simulations together with the experiments, Xu and Rao [14] analyzed if this method was appropriate for evaluating the friction condition of complex deformation of combined process. Recently the T-Shape test was developed by Zhang et al. [15-16]. Deformations including both extrusion and compression are involved in this test and only cylindrical surface of billet is in contact with the punch and the die. The surface expansion ratio may be up to 50%, the contact pressure can reach several times the flow stress of the material and the test is simple to perform in comparsion to the double cup extrusion test. Using this test Fereshteh et al. [17] evaluated the friction factor of a magnesium alloy at high temperature and found good results.

The objective of this paper has been to study the influence the contact pressure and surface enlargement have in the performance of glass coatings used for the hot forging of Ti64. It is well-known that glass coatings prevent oxidation and alpha case formation and reduce the friction coefficient. However, no publication has been found where the coating layer brakeage and its influences in the metal flow of the material have been analyzed, since the existing works using Ti64 and glass coatings have been performed using ring compression tests with small surface enlargement. In the present work ring tests and T-Shape tests are used in similar tribological conditions to see if the contact conditions are comparable in terms of friction behavior.

## 2. Materials and lubricants

The Ring tests and T-Shape tests of Ti-6Al-4V alloy were conducted at the deformation temperature of 940 ºC. Three surface conditions were studied: billets without coating, 40-45µm of CONDAERO 228 glass coating and 80-90 µm of the later coating. Every specimen was heated to the testing temperature in a Nabertherm 11 kW resistance furnace for 10 minutes. Once the test-piece reached its temperature conditions, the test-piece was transferred to the press and compressed between the dies to a predetermined stroke.

The forging tools were manufactured using the Uddeholm ALVAR14 tool steel (1.2714) hardened at 40 HRc. The tool system was maintained at a temperature of 200º C by means of a cartridge die heater (Hasco). A cartridge die heater (Hasco) is a digital temperature control box that was used to control the tool temperature during the test. Two thermocouple were placed between the dies and this digital temperature control box in order to keep the dies at a required temperature.

Before doing all the tests, the lubricant based on CONDAFORGE 625 graphite diluted in water to 10% using the pistol-spray was sprayed to the upper and lower dies. In the case of the ring tests stroke was set to obtain a 50% of height reduction. For the T-Shape tests, the press was programed to obtain a flange height (press gap) of 6 mm. Three replicates were produced for each testing condition in order to provide statistical meaning. After hot compressions, each sample was air cooled, cleaned and measured.

For the ring test samples, the inner diameter and the final height were measured. Since the most important variable for the coefficient of friction calculation is the inner diameter, a mean value of this dimension was measured in both directions at right angles, on both the specimens and at the middle in order to avoid the effect of the barreling on the accuracy of the friction factors. The average of measured value was used to calculate the percentage change of inner diameter.

For the T-Shape tests, the final width the samples present in the flat area of the forgings was used as the characteristic measure to calculate the coefficient of friction. The testing conditions are summarized in Table 1.

Table 1. Summary of the experimental tests.

| Test | Tool and billet material | Lubricant | Coating | Measurement |
|---|---|---|---|---|
| Ring test | Ti64 alloy at 940ºC<br>ALVAR14 hardened at 40 HRc (1.2714) at 200ºC | CONDAFORGE 625 diluted in water at 10% | No coating | Inner diameter reduction after 50% height reduction<br>Mean value of 3 repetitions |
| | | | CONDAERO 228 glass coating of 40-45 µm | |
| | | | CONDAERO 228 glass coating of 80-90 µm | |
| T-Shape tests | | | No coating | Flange width of flat area<br>Mean value of 3 repetitions |
| | | | CONDAERO 228 glass coating of 40-45 µm | |
| | | | CONDAERO 228 glass coating of 80-90 µm | |

## 3. Tooling and billet dimensions

The ring specimens were 30 mm outer diameter, 15 mm internal diameter and height of 10 mm considering 6:3:2 ratio that refers to D:d:h which is the most common and widely used ring. The ring dimensions and ring test tooling are shown in Fig. 1.

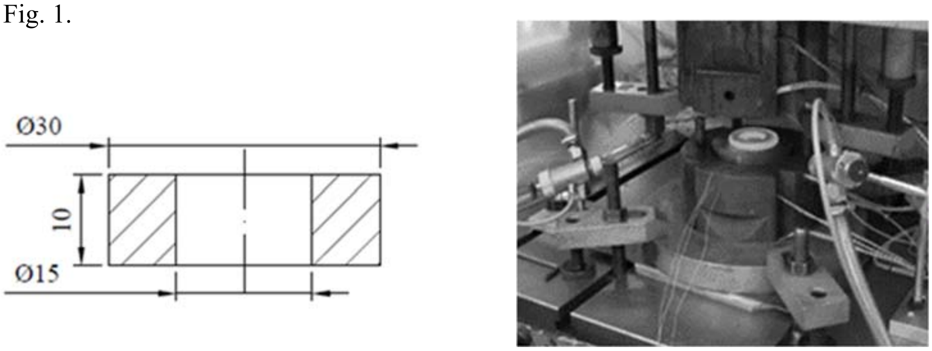


Fig. 1. a) Initial ring geometry and b) ring test tooling together with the water-graphite lubricant spraying system.

For the T-Shape test the lower die was machined with a V-shape groove by wire-cut Electrical Discharge machining (EDM), similarly to the ring-test flat tooling. Groove angle (β) is 15º, entry radius is 2.5 mm and total depth is 25 mm with a final radius of 1 mm. The groove dimensions and T-Shape tooling are shown in Fig. 2.

Surface roughness in both test-tooling systems is around Ra2.70 µm and the rotation speed of the mechanical press has been adapted to be 30 strokes/min for both tests.

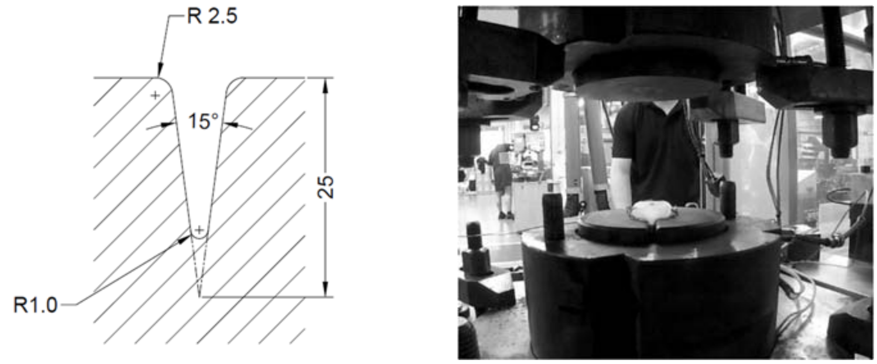


Fig. 2. a) Groove dimensions and b) T-Shape tooling together with the deformed specimen.

## 4. Numerical models

In order to identify the COF in the experiments explained before two numerical 3D models were created using FORGE3® finite element software. Both models use rigid tools being the specimen deformable with the material properties of the employed Ti-6Al-4V material. Air cooling was previously applied to the specimens in order to emulate the transfer time between the furnace and the tool. After this initial cooling step, with a duration of 4 seconds, a dwell time of 2 seconds was applied (waiting time) and finally the upper tool applied the mechanical press movement using the characteristic eccentricity and ram arm dimensions of the press.

In the case of the ring test simulation, symmetry was applied to the specimens in order to reduce the computational time needed to run the simulations. This way, only one eighth of the specimen was simulated. As explained before, the ring was deformed until getting a deformation of 50% in height. During the entire simulation, the evolution in height of the ring and the evolution of the internal diameter of the ring was monitored using the history data of two nodes. This way the relation between the internal diameter and the height was continuously plotted. The simulation was carried out for different coefficients of friction and the variation of the aforementioned relation was plotted.

In the case of the T-Shape test simulation, symmetry was also applied in order to reduce the computational time. In this case one quarter of the billet was simulated and the press gap was set to 6-7 mm (final web height). As in the previous simulation model the tools were considered as rigid and the evolution of the web height and the web width were continuously monitored using two nodes. Both models can be seen in Fig 3.

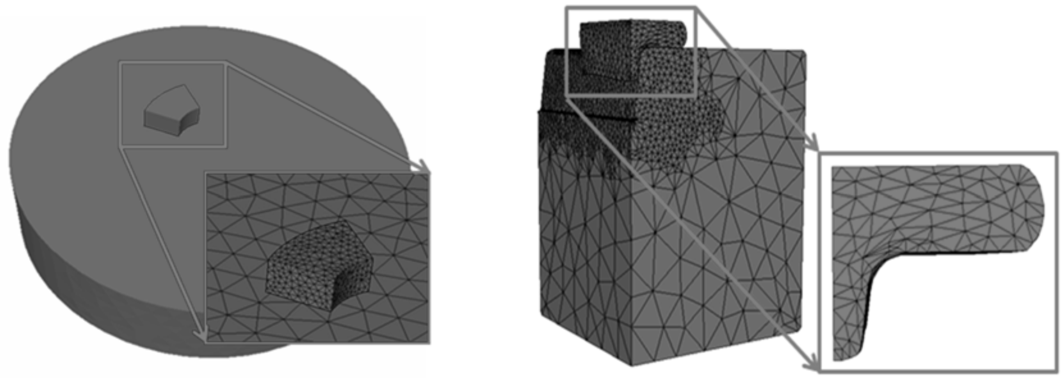

Fig. 3. Numerical model for a) Ring test and b) T-Shape test.

## 5. Results and conclusions

The evolution of the inner diameter with the ring height of the numerical simulations together with the final experimental measurements for the three surface conditions are shown in Fig 4. As it can be observed, the coated surfaces give a friction factor of approximately 0.3 meanwhile the uncoated ring is under the zone of friction factor 0.8-1.0.

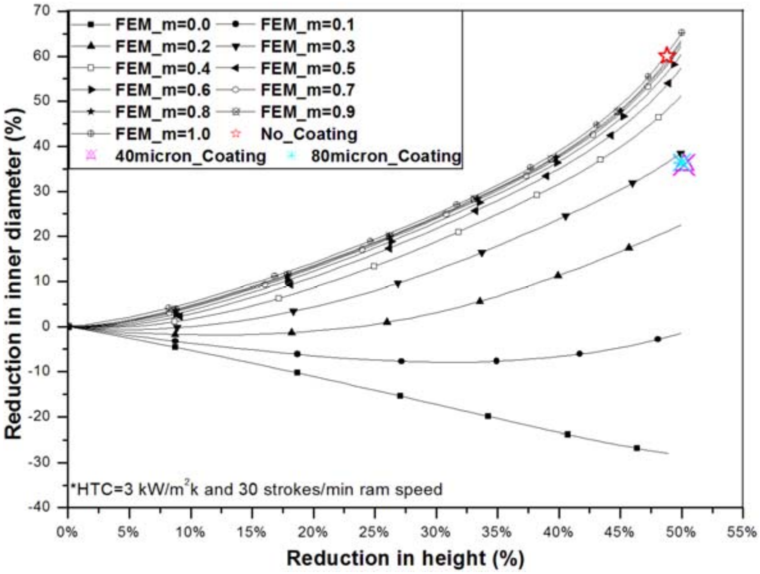


Fig. 4. Calibration curves and experimental data of ring tests.

For the calculation of the T-Shape friction factor inverse modelling was also used. Particularly the total width (w) evolution with flange height was plot for different friction factors obtained by numerical simulation and experimental values where evaluated within this graph. Unlike in the ring tests, billets having 80-90 µm glass coating gave a friction factor of approximately 0.4 while the billets having 40-45 µm glass coating result in a friction factor of 0.6. AS in the ring tests, the uncoated billets experimental measurements are under the zone of friction factor 0.8-1.0.

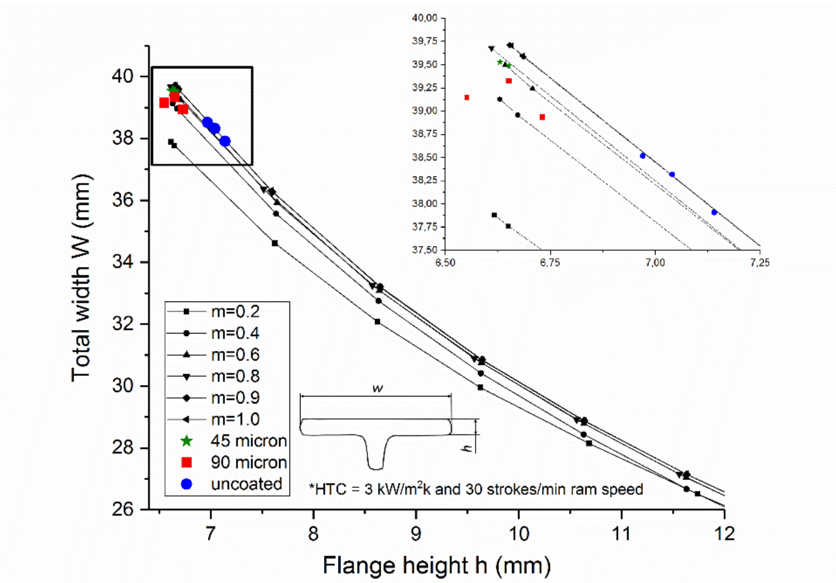


Fig. 5. Calibration curves and experimental data of T-Shape tests.

From the experimental results it is clearly observed that the contact pressure and specially the surface enlargement suffered by the material have a big influence on the friction factor. Bigger friction factors are obtained for bigger surface enlargement being the case of the T-Shape tests. In these tests, as the surface in contact with the tools are expanded the coating effect is lost in the new contact areas that are created since the glass coating is brittle and is not following the materials surface enlargement. This effect would explain the increase of friction factor since the new fresh material is uncoated being the friction higher in these areas.

As a general conclusion it is observed that T-Shape is a more sensitive test for testing glass coatings and could represent the real industrial applications more precisely.

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## References

[1] Bai, Q., Lin, J., Zhan, L., Dean, T. A., Balint, D. S., & Zhang, Z. (2012). An efficient closed-form method for determining interfacial heat transfer coefficient in metal forming. International Journal of Machine Tools and Manufacture, 56, 102-110.
[2] Wilson, W. R., Schmid, S. R., & Liu, J. (2004). Advanced simulations for hot forging: heat transfer model for use with the finite element method. Journal of materials processing technology, 155, 1912-1917.
[3] Hu, Z. M., Brooks, J. W., & Dean, T. A. (1998). The interfacial heat transfer coefficient in hot die forging of titanium alloy. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 212(6), 485-496.
[4] Male, A. T. (2002). Friction measurement using the ring compression test. In Proceedings of the Seventh ICTP Conference (Vol. 1, pp. 321-326).
[5] Nagpal, V., Lahoti, G. D., & Altan, T. (1978). A numerical method for simultaneous prediction of metal flow and temperatures in upset forging of rings. ASME J. Eng. Ind, 100, 413-420.
[6] Li, L. X., Peng, D. S., Liu, J. A., & Liu, Z. Q. (2001). An experiment study of the lubrication behavior of graphite in hot compression tests of Ti–6Al–4V alloy. Journal of Materials Processing Technology, 112(1), 1-5.
[7] Li, L. X., Peng, D. S., Liu, J. A., Liu, Z. Q., & Jiang, Y. (2000). An experimental study of the lubrication behavior of A5 glass lubricant by means of the ring compression test. Journal of Materials Processing Technology, 102(1), 138-142.
[8] Zhu, Y., Zeng, W., Ma, X., Tai, Q., Li, Z., & Li, X. (2011). Determination of the friction factor of Ti-6Al-4V titanium alloy in hot forging by means of ring-compression test using FEM. Tribology International, 44(12), 2074-2080.
[9] Mirahmadi, S. J., Hamedi, M., & Cheraghzadeh, M. (2015). Investigating Friction Factor in Forging of Ti-6Al-4V through Isothermal Ring Compression Test. Tribology Transactions, 58(5), 778-785.
[10] Geiger, R. (1976). Metal flow in combined can extrusion. Verlag Giradet, Essen.
[11] Barcellona, A., Cannizzaro, L., Forcellese, A., & Gabrielli, F. (1996). Validation of frictional studies by double-cup extrusion tests in cold-forming. CIRP Annals-Manufacturing Technology, 45(1), 211-214.
[12] Schrader, T., Shirgaokar, M., & Altan, T. (2007). A critical evaluation of the double cup extrusion test for selection of cold forging lubricants. Journal of materials processing technology, 189(1), 36-44.
[13] Petty, D. M. (1994). Friction models for finite element modelling. Journal of materials processing technology, 45(1-4), 7-12.
[14] Xu, W. L., & Rao, K. P. (1997). Analysis of the deformation characteristics of spike-forging process through FE simulations and experiments. Journal of materials processing technology, 70(1-3), 122-128.
[15] Zhang, Q., Felder, E., & Bruschi, S. (2009). Evaluation of friction condition in cold forging by using T-shape compression test. Journal of Materials Processing Technology, 209(17), 5720-5729.
[16] Zhang, Q., Arentoft, M., Bruschi, S., Dubar, L., & Felder, E. (2008). Measurement of friction in a cold extrusion operation: Study by numerical simulation of four friction tests. International Journal of Material Forming, 1(1), 1267-1270.
[17] Fereshteh-Saniee, F., Badnava, H., & Pezeshki-Najafabadi, S. M. (2011). Application of T-shape friction test for AZ31 and AZ80 magnesium alloys at elevated temperatures. Materials & Design, 32(6), 3221-3230.