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DETERMINATION OF FRICTIONAL COEFFICIENT OF 316L (N) STAINLESS STEEL BY RING COMPRESSION TEST USING SIMULATION

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ABSTRACT

In metal forming, coefficient of friction plays a vital role in plastic forming of material. Mechanical properties also influence the forming processes. Further, Frictional coefficient affects the microstructure of finished material, tool wear and decides the amount of energy needed for forming. This study enables to compute the adhesion friction factor during plastic forming. Usually, Standardized specimen dimensions (6:3:2), derived from Plasticine model of has followed for experimental studies. The ring compression test takes into account the percent change in inner diameter to the percent change in height. Experimentation was carried on 316L (N) specimens of dimension (12:6:4) mm at dry conditions in temperatures ranging 900, 1000, 1100, 1200°C. After the ring compression, the final dimensions were calculated by Vernier caliper and LEXT 3D laser confocal microscope to compare the results effectively. Validation was carried out in ABAQUS software.

Key words: *316LN stainless steel, ring compression test, 3D laser confocal microscope, coefficient of friction, bulk forming process, FEA, ABAQUS.*

1. Introduction

Austenitic stainless steels are important structural material that have been extensively used in high temperature components of fast breeder reactors, mainly because they sustain their mechanical properties even at high temperature, superior corrosion resistance, adequate weldability, and low cycle Fatigue strength and creep resistance. Austenitic stainless steels also account for the largest quantity of all stainless steels produced because they find a wide range of applications and are characterized by attractive mechanical properties such as corrosion resistance by virtue of their high chromium content, high creep strength, oxidation resistance, good low-temperature toughness high degree of formability and weldability. Using mathematical relationship, different curves were developed by Male and Cockcroft which was later called as friction calibration curves. Coefficient of friction was tending to increase with an increase rate of deformation during dry condition. Several etalon curves were considered from various authors and similar comparison was done using experimentation [1]. Male and Cockcroft has experimentally developed friction calibration curves in which percent reduction in diameter versus percent reduction in height of specimen is considered. This method is used for metal forming particularly under high temperature conditions. Greater advantages were obtained using softer material of flow stresses lower than metals in the study of metal forming problem. Less expensive tools, easy data acquisition is a plus point in the above material selection [2]. With the mathematical formula stated by Avitzur [3] and Hawkyard Johnson the coefficient of friction **μ** was computed [4]. Wanheim has developed a method to determine friction in all areas including medium pressure ranges [5]. Contact friction plays a vital role in plastic forming of material apart from material properties and forming load. These influences can be seen in the microstructural changes of material, tool wear and increase in the energy for forming. Because of complex behavior of friction conditions during the forming, formation of mathematical equations is difficult to describe friction. This paper will help us to understand the tribological problems in forming problems. The first approach is to define the friction mechanism and development of methods for integrating these into models. For mathematical definition of friction problems three laws are approached: 1) Amonton’s and Coulombs law, 2) Law of constant friction and 3) Adhesion theories.

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First model is defined as µ-model; the second is called as m-model, the third model f-model [6]. In ring compression tests, inner diameter of the ring increases in the same manner as the outer diameter when friction is zero. But it will reduce when the friction value reaches a critical value [7]. A ring of standard dimension is also tested in the same machine. When compared, standard ring specimen with other specimens, it is observed that the geometry of specimens which consist of any geometrical shape inside circle, give very close friction value [8]. The friction coefficient is sensitive to specimen geometry. It decreases with reduction in height and outer radius and increases with inner radius [9]. However, the actual values of m obtained by using theory to analyze experimentally determined shape changes appear to be somewhat in error to a degree depending on the initial specimen geometry and the general friction level under which it is deformed [10-13]. Less attention has been paid barreling effect during deformation and dependency of friction calibration curve on material properties and material deformation conditions. Several different methods are there with which it will become easier to determine coefficient of friction such as complementary ring compression test, where the ring geometry is taken in such a manner that even the smaller stresses can be realized. In this study, the ring compression test was used to compute the coefficient of friction in high temperature conditions for 316 L(N) stainless steel.

2. Methodology

Initially, 316L (N) ring specimens of dimensions 12:6:4 mm were fabricated. Outer diameter is 12 mm, inner diameter is 6 mm and height is 4 mm. Ring specimens were compressed between two platens. Compression testing machine (BISS, Bangalore) was used along with a data acquisition system. 50% reduction in height was chosen with 0.01/s strain rate [9]. Before the experimentation, the ring specimens the initial inner and outer diameter and the initial height of the specimen were measured using vernier calipers. Later as the specimens were tested using compression testing machine, one by one at the specified temperature namely 900°C, 1000°C, 1100°C, 1200°C.

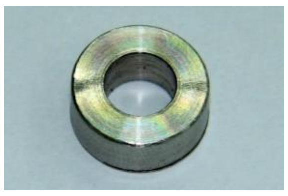

Figure 1: Initial Ring specimen

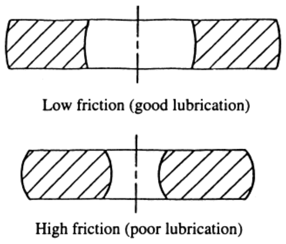

Figure 2: Frictional conditions

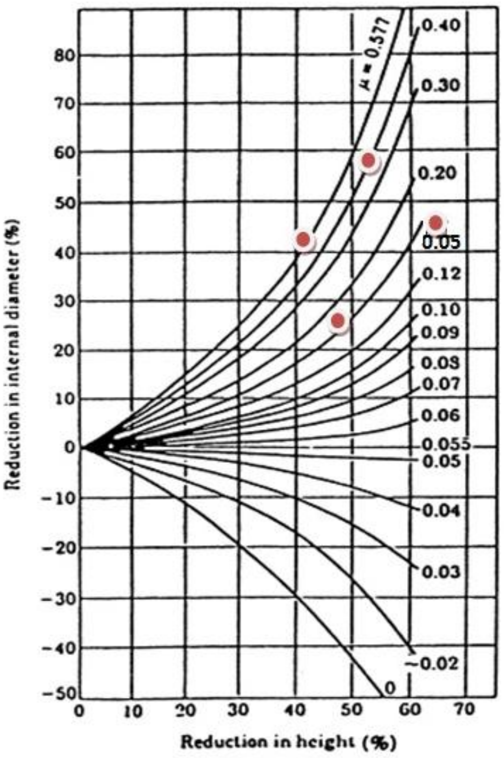

Figure 3: Coefficient of Friction

Each of the specimens was kept for a soaking period of 5 minutes before the actual compression takes place. As soon as the compression was over the compressed specimen was water quenched, after that the final inner diameter, final outer diameter and the final height of the specimens was measured. After getting the final specimen dimensions in the ratio OD: ID: HH, percentage reduction of inner diameter and percent reduction in the height was plotted in the below stated calibration curves and the respective m-factor was noted. With the mathematical formula stated by Avitzur

[3] and Hawkyard Johnson we have found out the coefficient of friction µ. [4] Simulation of the above experimentation was carried out in Abaqus/Standard where the dies were considered as a analytical solid with a reference point at the outer periphery. CAX4RT element was taken as for the axisymmetric ring compression test. The ring was finely meshed with mesh element size of 0.5 so as to converge to the solution effectively. All the degrees of freedom of the bottom die were arrested and the top die was given a vertical displacement of 2 mm downwards. The ring was compressed for 50% of its initial height.

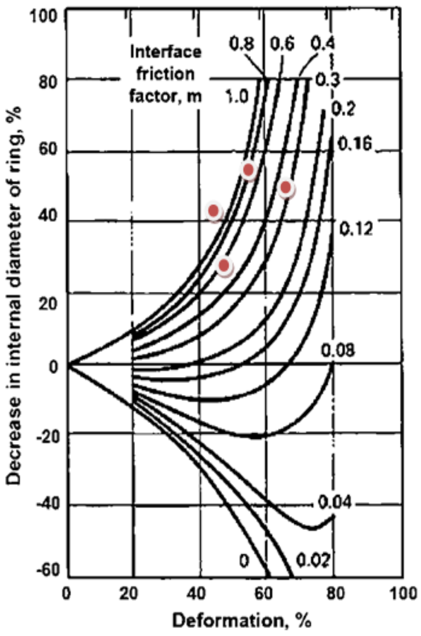

Figure 4: Friction factor calibration curve

3. Results and Discussion

In ring compression tests, high frictional values and large amount of heat evolution predominant in tool and work piece interface. It influences the forging force, die wear, forming quality and deformation mechanism under dry conditions. Table 1 shows change in outer diameter (increase in dimension), change in inner diameter (decease in inner diameter) and the change in height (decrease in height). Using the measured values, reduction in inner diameter, height and m factor are calculated [10]. The values are tabulated in Table 2. The effect of temperatures in coefficient of friction tests were calculated and shown in Table 3. The lower coefficient of friction in higher temperature 1200°C is due to the thermal softening which increases the material flowability under compression loads. Figure 2 gives the correlation of the results making us to conclude that the increase in inner diameter in ring compression test demonstrates higher frictional conditions. It’s again a clear distinct feature of compression testing at dry condition. The above procedure was simultaneously carried out in FEA software to verify the results obtained from experimentation with the simulation results. In frictionless condition the inner radius (R_i) of the ring was moving outer to the proven mean radial diameter (R_n) and the von-mises stresses in the ring specimen found to be 292 MPa which is lesser than the yield strength of the stainless steel material 316L(N), (σ_y)=300MPa. Whereas, during friction condition the von-mises stress values are 320 MPa which is greater than the yield strength value of SS316L (N) and hence the greater distortion of the specimen was observed.

Figures (5-8) shows the laser macrograph captured from the deformed ring specimen at 900-1200°C for representative purpose. Figure 9 shows the three dimensional surface plot of the compressed ring specimen.

Table 1: Analytical Experimental results

TEMP °C	*CONDITION*	*Decrease in ID*	*Increase in OD*	*Decrease in height*
900	DRY	2.455	2.691	1.969
1000	DRY	3.72	3.56	2.13
1100	DRY	3.83	4.09	2.14
1200	DRY	3.01	3.01	2.11

Table 2: Reduction in ID vs. Reduction in height

TEMP °C	*% REDUCTION IN INNER DIAMETER*	*% REDUCTION IN HEIGHT*	*m-FACTOR*
900	40.38	40.63	1.04
1000	47.36	64.11	1.59
1100	58.75	53.05	1.42
1200	25.90	48.26	0.97

Table 3: Coefficient of friction

Temperature °C	*Condition*	*Coefficient Of Friction*
900	DRY	0.39
1000	DRY	0.46
1100	DRY	0.41
1200	DRY	0.28

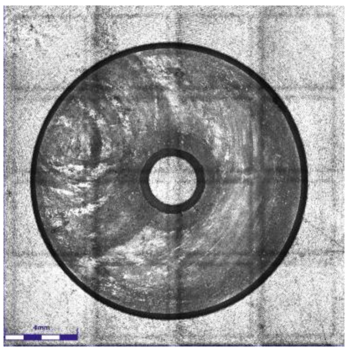

Figure 5: Laser Micrograph (900°C)

Figure 6: Laser Micrograph (1000°C)

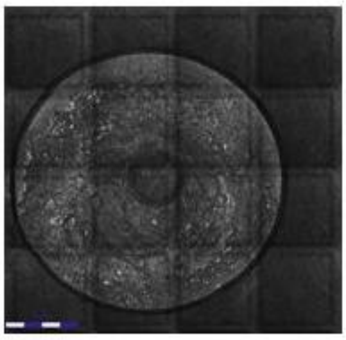

Figure 7: Laser Micrograph (1100°C)

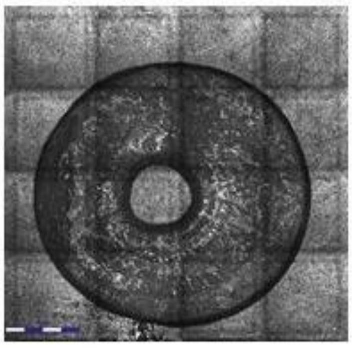

Figure 8: Laser Micrograph (1200°C)

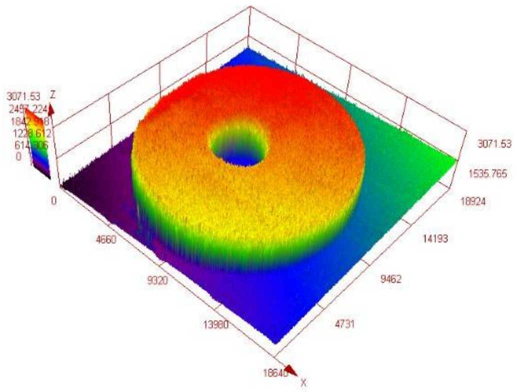

Figure 9: 3D Surface plot of deformed specimen

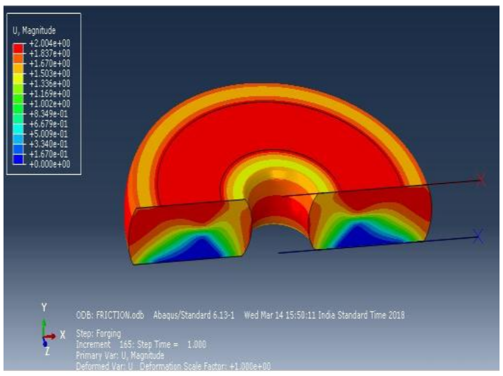

Figure 10: Displacement of material in ring specimen

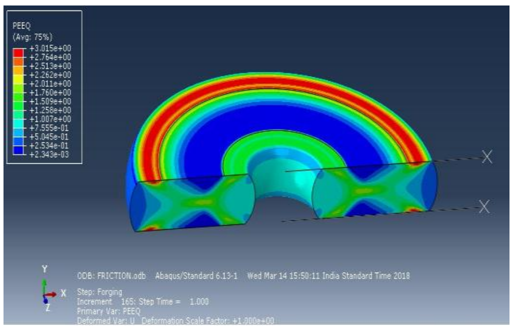

Figure 11: PEEQ in ring specimen

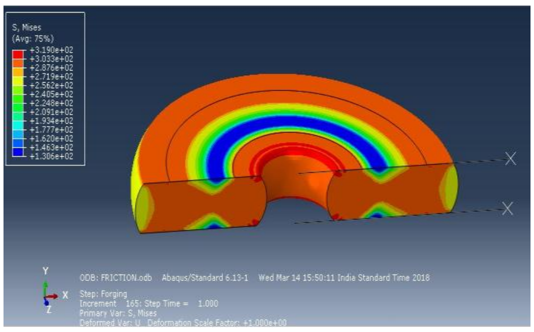

Figure 12: Von-mises stresses in ring

Figure 10 shows the displacement of material in ring specimen. Figure 11 portrays the PEEQ of the ring specimen. PEEQ - Equivalent Plastic Strain is a scalar quantity. It is a representation of a tensor. Figure 12 depicts Von-mises stresses in ring. The values are in good regard with the experimental values. The simulation results are correlated with the experimental results.

4. Conclusion

In this research work, friction coefficient and friction factor in dry condition at various different temperatures were calculated. Coefficient of friction initially increases and has a gradual decrease with increase in temperature. During 1000°C-1100°C it increases with decrease in the inner radius and increases with reduction in height of the specimen and it also increases with tool surface roughness. Tool surface roughness is the most important factor for determining friction coefficient during dry condition. At 1200°C, there is a rapid decrease in the friction coefficient along with the drop in the forming load which was attributed by thermal softening and enhanced material flowability.

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