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SIMULATION OF UNIAXIAL COMPRESSION OF A CYLINDRICAL BILLET AT ELEVATED TEMPERATURES USING FEA

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ABSTRACT

A cylindrical specimen was designed and simulated using FEA method to understand the uniaxial compression process at different temperatures and frictional conditions. Mechanical Properties of SS 316 L(N) were chosen for the study. ABAQUS/Standard, a finite element modelling software was used to demonstrate the material behavior under bulk-metal forming process. In compression testing, the working temperature influences the frictional coefficient in the interface of the die platen and the specimen which in turn plays a crucial role in the barreling of the specimen. A conical wedge of a relatively undeformed metal (dead metal zone) is formed immediately below the contact faces, while the rest of the cylinder metal suffers high strain hardening and bulges out in the form of a barrel. Simulation was carried on a cylinder whose L/D ratio is 1.5 under normalized compression boundary conditions and four different temperatures namely, 550,650,750 and 850°C. From the simulation results, it was found that the friction in the die-specimen interface increases with the temperature during barreling phenomenon. The von-misses stress and plastic equivalent strain values by the simulation were found to be in good regard with the experimental values.

KEYWORD: ABAQUS, Uniaxial Compression, Barreling Effect, Temperature, Frictional Conditions

In upset cold forging, the existence of frictional constraints between the dies and the work piece directly affect the plastic deformation of the latter. Forging is the process of compressing a specimen in between two dies of flat profile. For compression tests generally cylindrical specimens are mostly preferred. To determine the workability of the material in bulk forming, compression testing is carried out. Upset forging is the process that is being used to produce work pieces that are having strength comparatively higher than casting or machined part. Mostly work pieces of wire or rod are used but even bars can be feed having a diameter range upto 9.8 inches. Compression test including ring test, axisymmetric and plain strain have considered for finding out the material deformation behavior including different aluminum [Onawola and Adeyemi, 2003], its alloys [Chen et. al., 2004], steels [Hw et. al., 1993], nickel based super alloys [Kang et. al., 2008], and non-linear geomaterials such as rock [Nawrocki et. al., 1998]. For reproducing the actual compression of a cylindrical billet into an FEA model, actual forging process was kept in mind and different parameters was taken into Abaqus/Standard. The displacement of the specimen along Z-direction can be estimated from:

$$\varepsilon_Z = \frac{UZ}{LZ} \quad \text{and } E_Z = \frac{\sigma Z}{\varepsilon Z}$$

Where UZ is the displacement along Z-direction and LZ the length of specimen. The poison ration of 0.35 and Young's modulus of 200 GPa were considered as per the unified data [Cadena and Alfonso, 2014]. Operating temperature for austenitic stainless steel is considered greater than 427°C for its desired mechanical properties [Mannan et. al., 2003] and corrosion resistance at radioactive environments [Matula et. al., 2001]. During design and fabrication of a component, it is important to consider the flow behavior of the material which enables to understand the mechanical properties. For generating FEA code it is very important to find the properties in order to simulate the exact flow behavior of the material under real working condition. To select a suitable model from the existing constitutive models or to develop a new one, it is necessary to understand the response of the material to loading at different temperatures and strain rates. It was understood that, with increase in strain, the flow stress of the material increases up to a certain strain level after which the stress saturates. This increase in flow stress is attributed to the strengthening of the material due to work hardening [Kumar et. al., 2017]. Flow behavior depends largely on temperature, strain and strain rates [McQueen and Ryan, 2002] along with various parameters that changes with chemical compositions and working conditions. In this work, it was attempted to study the barreling behavior of the cylindrical specimens at different working temperatures during uniaxial compression test. Frictional coefficients obtained from the experiments

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were incorporated in the simulation of the compression testing of SS 316L (N) steel.

METHODOLOGY

A cylindrical solid specimen of Ø 10 x15 mm which confines to the L/D ratio of 1.5 was considered. The finite element model consists of hexahedral mesh element with 0.5 mm length using reduced integration method. Both top and bottom die platens have been considered as a discrete solid having a quadrilateral mesh element of size 1.5mm. The body property was applied at the center of the die platens. ABAQUS/Standard is used as a pre-processor, solver and post-processor software. For simulating compression testing, four specimens were chosen at different temperatures namely 550, 650, 750, and 850°C were used. Upper die displacement was constrained to 50% of the total specimen length. Lower die was restricted at all degrees of freedom. Surface contact initialization in between the interface of the die surface and specimen cylinder was fixed as (top and bottom faces) 0.2-0.35, from the experimental values. Elastic modulus of SS 316 L(N) was 200GPa and the corresponding Poisson's ratio was 0.35 with density of 7.99E-03 Kg/mm3. Different temperatures are applied to the model under predefined field. Figure 1-3 shows the schematic sequence in the uniaxial compression. Table 1 shows the frictional coefficient values taken form experimental results and the same were incorporated during the compression simulation.

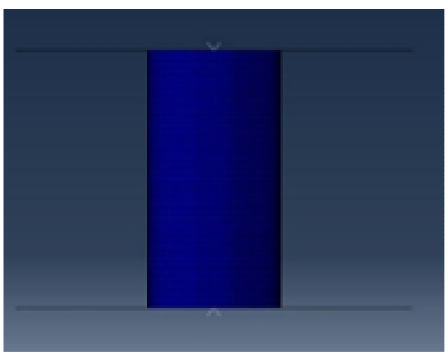


Figure 1: Initial specimen

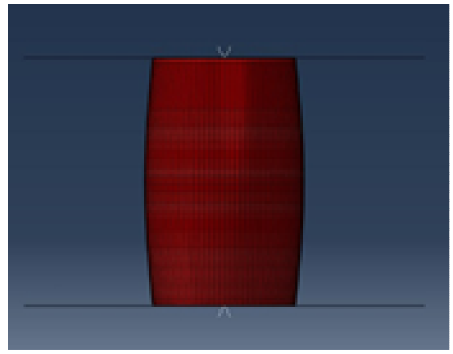


Figure 2: Intermediate

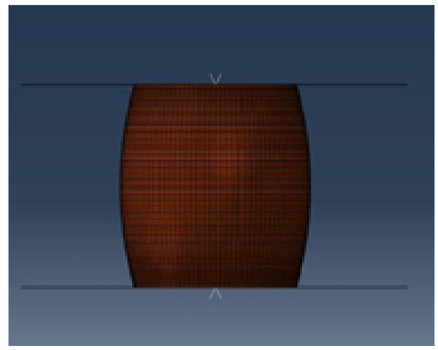


Figure 3: Intermediate

Table 1: Coefficient of friction at different temperatures obtained from compression testing experiments

Sl No	Temperature	Frictional Coefficient
1	550°C	0.20
2	650°C	0.25
3	750°C	0.30
4	850°C	0.35

RESULTS AND DISCUSSION

Figure 4 shows variation of Von-Mises stresses with respect to the operating temperatures. The plot shows that Von-Mises stress values decreases with increase in the operating temperature in compression testing. The Von Mises stress is related to this total stress component going into the distortion energy.

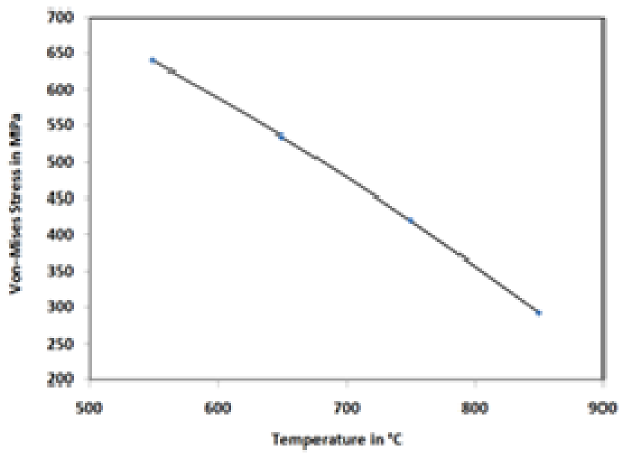


Figure 4: Variation of Von-Mises stresses with respected to operating temperature

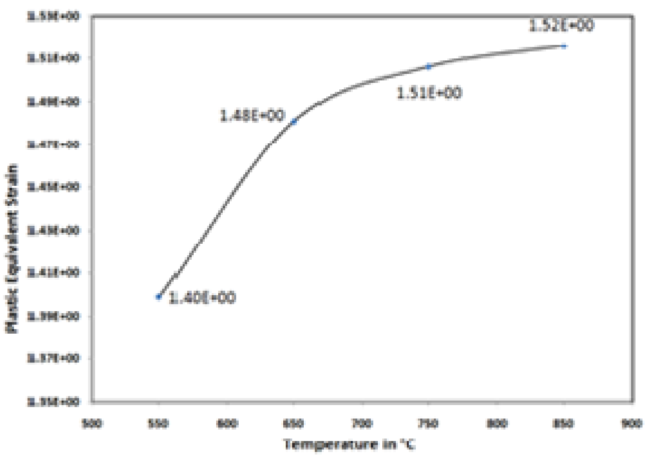
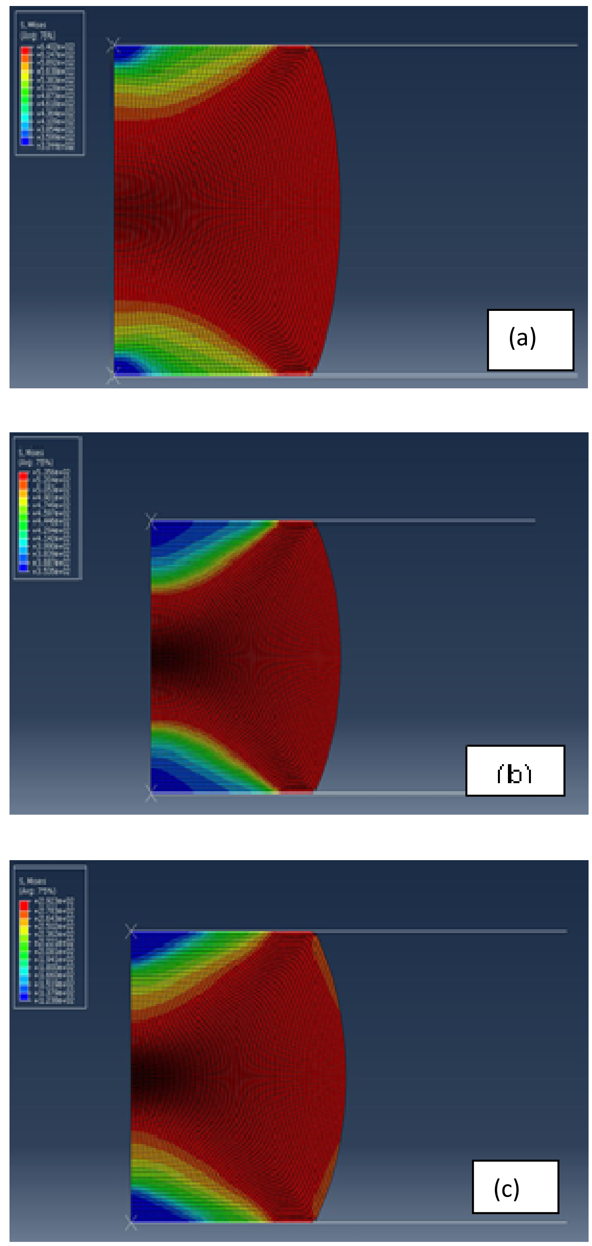


Figure 5: Variation of Plastic Equivalent strain with respect to operating temperature

As the operating temperature increases in the compression testing, the cylindrical specimen showed lesser Von-misses stress values. During compression test experiments, the higher operating temperature promotes the rate of dislocation during barreling and thereby it attributes the reason for lesser Von- Mises stress values in the cylindrical specimens. The same trend was shown in the simulation results also. Figure 5 shows the variation of equal plastic strain with respect to operating temperature during compression tests. The graph shows the steep climb of strain values in the high temperature operating zone in compression test (850°C). Figure 6 (a-d) shows the simulation images of the compression specimen at various temperatures namely 550°, 650°,750° and 850°C. Figure7 (a-d) shows the variation of equivalent plastic strain with respect to various temperatures. Though higher frictional coefficient (0.35) hinders the metal forming (barreling) ability, it was surpassed by the enhanced rate of dislocations due to the high operating temperatures.



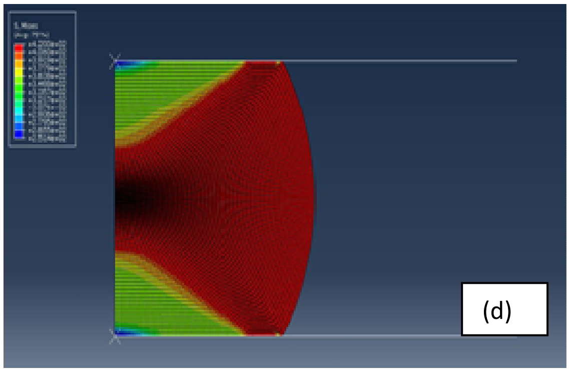
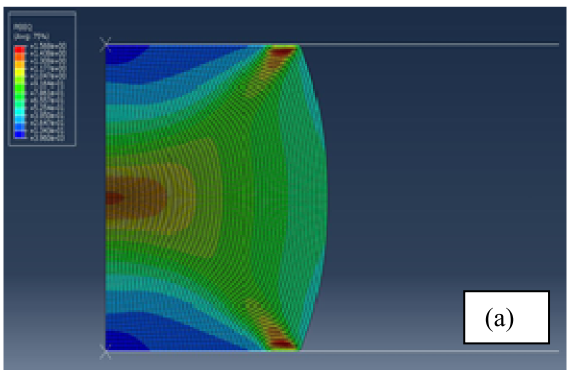
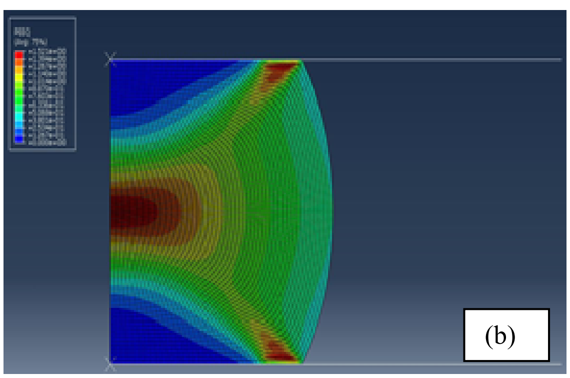
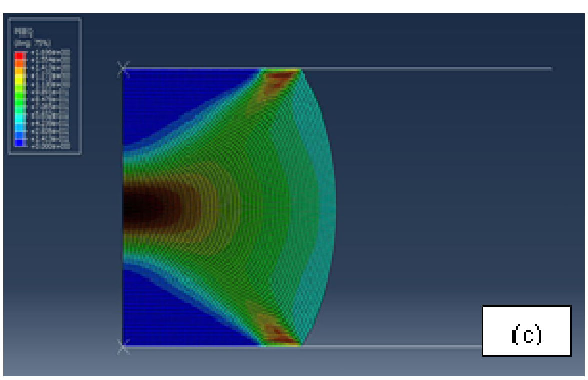


Figure 6: Simulation image of compression specimens at (a) 550° (b) 650° (c) 750° (d) 850°C







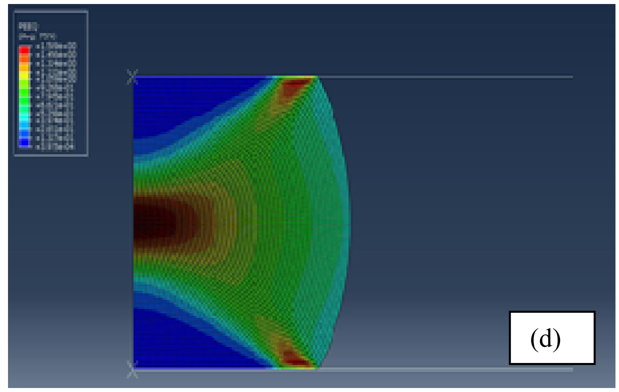


Figure 7: Variation of Plastic Equivalent strain with respect to temperature (a) 550° (b) 650° (c) 750° (d) 850°C.

CONCLUSION

From the above simulation results incorporating the experimental values and constraints, the following conclusions were drawn.

- During the uniaxial compression of the billet, the flow stresses at the central portion of the specimen are getting reduced as the material flow takes place at the outer periphery of the billet.
- Though the coefficient of friction increases with temperature, and hinders the flow of metal at both the ends the specimen experiences higher strain rate due to thermal softening.
- Von-Mises stress values of the cylindrical specimen decreases with increase in operating temperature because of the enhanced dislocation during the compression testing.
- Plastic equivalent strain shows an increasing trend with the increase in operating temperature.

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