Workability Study on Austempered AISI 1018

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Abstract: Workability of a material is a complex technological concept that is related to both material and process characteristics. Austempering is a heat treatment process that is applied to ferrous metals, mostly steel and ductile iron. The present work was carried out to study the workability and the properties of AISI 1018 steel in austempering and annealing condition and then comparing with each other. Workability testing was carried out using collar type specimen by compressing it till the crack. Workability diagrams have been plotted as a function of axial and hoop strains at failure. The result shows that, the austempering process increases the tensile strength and hardness as well as the workability. Thus the austempering process has an effect on strength and hardness.
Keywords: AISI 1018 Steel, Austempering,, Annealing, Compression test, Workability limit.

1. Introduction

The steel is classified as low carbon steel, medium carbon steel, high carbon steel on the basis of carbon content. Low carbon steel has a carbon content of 0.15% to 0.3%. Low carbon steel is the most common form of steel as it provides material properties that are acceptable for many applications. It is neither brittle nor ductile due to its lower carbon content. It has lower tensile strength and malleability. As the carbon content increases, the metal becomes harder and stronger but less ductile[1].Carbon steel is used in boilers, pressure vessels, heat exchangers, piping, in which good strength and ductility are desired[2]. The workability limit in metalworking is a complex phenomenon that depends both on the material and the deformation process parameters. Workability is a term used to define the degree of deformation during a metalforming operation that a material can be subjected to without failure. Ductility of a material is generally defined by the strain at fracture. In metalworking applications, ductility is not a unique property of the material; it depends on the local state of stress and strain rate in combination with material characteristics such as microstructure, inclusion content and morphology, grain size and the condition along toolwork piece interface[3]. Figure 1 shows workability limit for a material, here the area under the workability limit line is a safe limit line and the area above the fracture limit line is not safe.If we trace strain path 1 then fracture may occur at point A for a material Y and point B for a material X. Inorder to get higher strains the processing condition were changed, if we see the strain path 2 for material Y the fracture occurs at a point C and for material X fracture occurs at a point D[4].
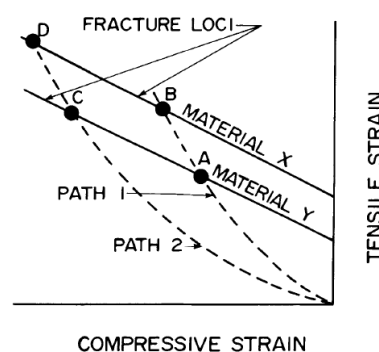

Figure 1. Superposition of fracture loci and strain paths[4].

2. Experimental Procedure

2.1 Materials

The workability experiments were carried out in steel. The as-received steel had been in the form of 20mm diameter and 1000mm long. The as-received material was checked for its chemical composition by using an optical emission spectrometer, which was carried out at servel engineer, Mangalore, India. Composition details are shown in Table 1.

Table 1. Chemical composition of the specimen used for the test (wt-%).

Fe	C	Mn	P	S
98.6%	0.18%	0.53%	0.037%	0.031%

To perform austempering heat treatment, the as received samples were first austenitised at 950°C for 60 minsin a high-temperature furnace. The furnace temperature was controlled to±5° of the set temperature value. The next step is isothermal holding, which was carried out in a resistance-heated salt bath furnace, which was controlled to±5° of the set temperature value. The salt mixture consisted of 55% KNO_3 and 45% $NaNO_3$ by weight. This composition has awideworking temperature range varying from222 to 540°C.The temperature maintained in this salt bath is 360°C for 60 mins[5].To perform annealing heat treatment, the as received samples were first heated to 700°C for 60 minsin a high temperature muffle furnace. After that it was cooled in a furnace itself so that it was cooling down at a very slow rate[6].This heat treated specimens were metallographically polished and etched using 2% nital and were characterized at optical microscope and at higher magnifications using a JEOL JSM-6380LA scanning electron microscope (SEM).

2.2Determination of MechanicalProperties

For hardness measurement, Rockwell hardness machine with B scale were used in order to determine hardness by using 100 N load applied for 30 Sec. Average hardness reading was noted by taking five hardness readings at different positions. For tensile test the specimens were prepaid as per the ASTM E-8 standards and specimens were tested in a Shimadzu AG-XplusTM 100KNuniversal testing machine with a fixed crosshead speed of 2mm/min and tensile properties like percentage elongation, ultimate tensile strength were determined. Compression tests were conducted to the heat treated samples in order to determine the strength coefficient,strain hardening exponent and flow curve [7]. A 400KN universal testing machine was used for the compression tests.Cylindrical specimens of height to diameter ratio 1.25 were prepared.
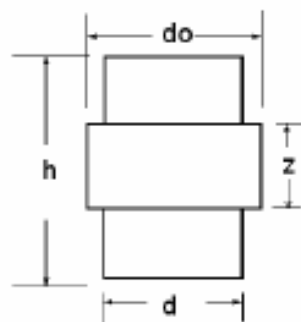

Figure 2. Diagram of collar specimen

2.3Workability study by upsetting test

In order to determine the fracture limit or workability limit, first the collar cylindrical shape specimens were prepared from heat treated rods. Diagram of the cylindrical collar samples has shown in figure 2.Dimensions of the specimens used for the upsetting test are shown in table 2.Upsetting or the compression tests were carried out in step by step process, and this process is continued until the crack was observed by our naked eyes on the outer surface of the samples. From the initial height and final height of the cylindrical collar specimen the axial strain was determined and the average diameter of three or four different sides of the cylindrical collar after fracture and initially were noted in order to determine the hoop strain. The strain path was plotted between axial strain and hoop strain. The axial strain were computed from $\varepsilon_1 = \ln(h_1/h_0)$ and hoop strain from $\varepsilon_2 = \ln(d_1/d_0)$. The last point on each strain path indicates fracture point and joining all these fracture points gives workability limit diagram[8-11]**.**

Table 2. Dimensions of ten different collar specimen.

Specimen height (h)	Diameter of collar (d_0)	Diameter (d)	z
20.0	16.0	12.8	5.0
18.7	15.0	12.0	4.6
18.1	14.5	11.6	4.5
17.5	14.0	11.2	4.3
16.3	13.0	10.4	4.0
15.6	12.5	10.0	3.9
15.0	12.0	9.6	3.7
14.5	11.6	9.2	3.1
14.0	11.2	9.4	3.5
12.5	10.0	8.0	3.1

3. Results

The microstructure of AISI 1018 steel in annealed and austempered condition has been shown in figure 3. In the annealed condition the microstructure shows Proeutectoid ferrite and pearlite.The function of annealing is to restore ductility and also removes internal stresses. After austempered at 360°C for one hour, the microstructure shows the bainitic morphology, because of the formation of bainitic morphology the strength of the specimen increased.
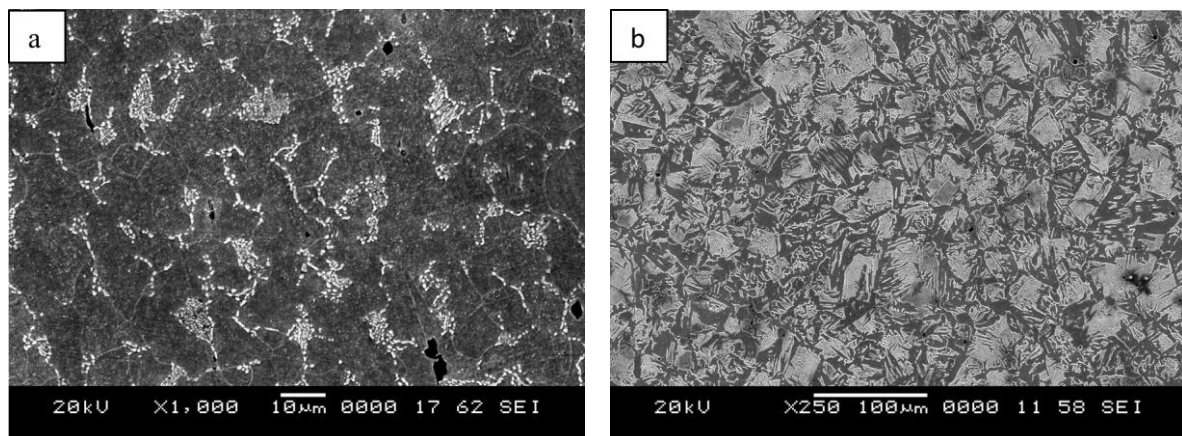

Figure3.SEMmicrograph a) Annealed condition(X1000) and b) Austempered condition(X250).

The Rockwell hardness graph as shown in figure 4. The hardness in the annealed condition is 44 HRB, and in austempered condition 55HRB. By austempering heat treatment process, the hardness, increased when compared with the annealed heat treatment process.
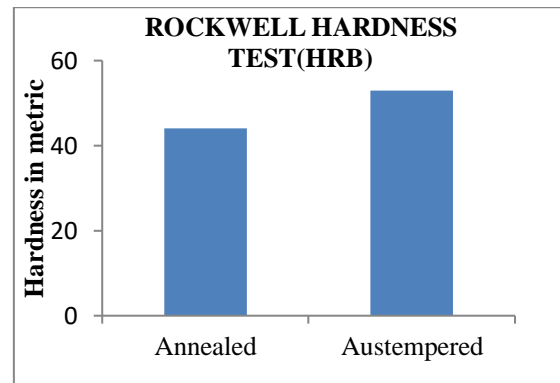

Figure 4. Hardness comparison graph.

The flow curves were obtained from compression test by plotting true stress vs true strain as shown in figure5. Flow curves were drawn from force-stroke data and these data were fitted to the power law equation$\sigma = k\varepsilon^n$. The values of 'K' and 'n' extracted from log stress vs log strain, the values have shown in table 3.Here in annealed condition we got 'K' value 928MPa and in austempered condition 961MPa. Therefore the strength in austempered condition has slightly improved when compared with annealed condition.
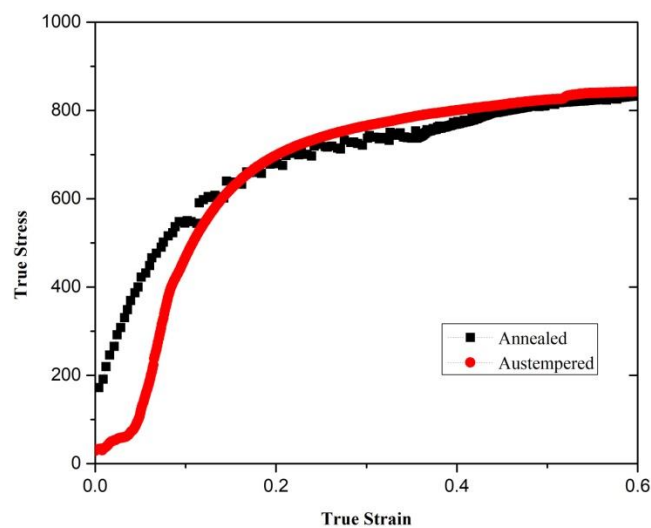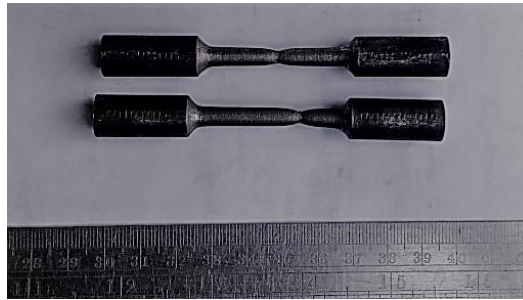

Figure5.Flow curves of AISI 1018 steel in annealed and austempered condition.

The tensile test results have shown in table 4. The ultimate tensile strength has improved after doing austempering heat treatment process. The ultimate tensile strength in annealed condition was 428 MPa and it increased to 492 MPa after austempering. But percentage elongation for annealed condition is 19%, and after austempering heat treatment decreased to 13.8%.

Table 3. The values of K and n measured from flow curves.

Conditions	K (MPa)	n
Annealed	928	0.23
Austempered	961	0.26

Figure 6. Specimens after tensile testing

From table 4 we can say that by austempering process, the hardness, yield strength, ultimate tensile strength increases and decrease in percentage elongation when compared with annealing process.

Table 4. Mechanical properties of heat treated steel

Heat Treatment	Hardness Test(HRB)	Tensile Strength(MPa)	Percentage Elongation(%)	Percentage Reduction in area (%)	Yield Strength(MPa)
Annealed	44	428	19	46	331
Austempered	55	492	13.8	44.8	334

The workability testing specimen before and after upsetting as shown in figure 7, in this, straight longitudinal crack was observed. From the workability tests on the AISI 1018 steels, the axial strain and circumferential or hoop strain values were noted and the graphs were plotted between them. Ten strain paths obtained from each type of heat treated condition, as shown in figure 8. The end points of all strain paths considered as the fracture points. Joining all this fracture point gives the workability limit for steel. The workability limit as shown in figure 9, in this figure, the area under workability limit is a safe limit and the area above the fracture limit is not safe for mechanical working processes.

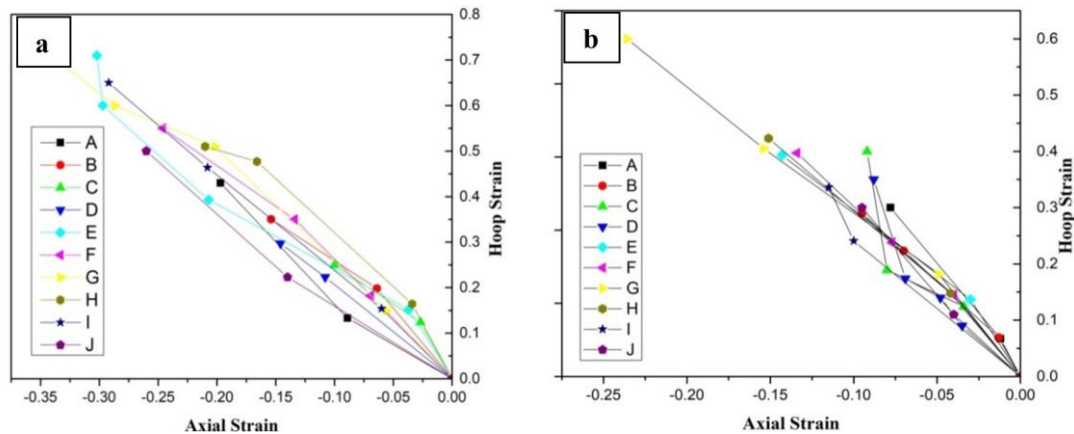**Figure 7 .** Specimens (a) Before upsetting, (b) and (c) after upsetting

Figure8. Strain paths (a) Annealed Condition, (b) Austempered Condition
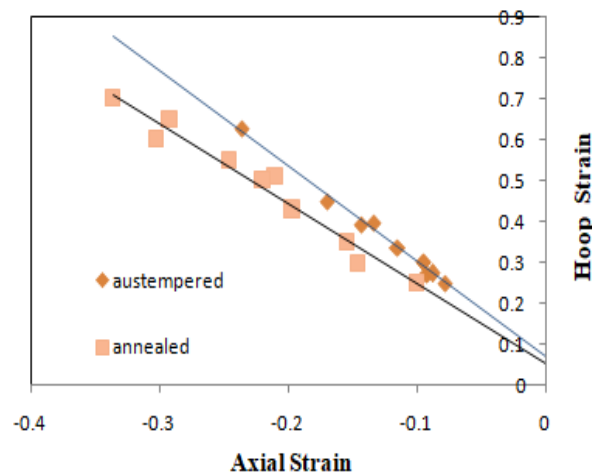

Figure 9. Workability limit diagram for annealed and austempered steels.

The workability limit of austempered AISI 1018 steel is above the annealed steel.Therefore the austempered steel has a better workability when compared with annealed steel.The workability results indicate that the combination of tensile strength and ductility properties associated with optimum microstructure consists of bainitic structure obtained after austempering of AISI 1018.

4. Conclusion.

The Austempering heat treatment process improves the tensile strength and hardness, but ductility decreases slightly.The tensile strength increases from 428 MPa to492 MPa andhardness, increased from 44 to 55 HRB in austempered condition when compared with annealed condition, and ductility decreases from 19% to 13.8% in austempered condition.Wokability data in conjunction with the mechanical properties determined by tensile and compression testing can be used to determine desired mechanical properties along with adequate workability. The workability limit is a useful tool in the design and manufacture phases of any product. The workability limit of austempered AISI 1018 steel is above the annealed steel, even though the duclility of the specimen slightly decreased because of increases in strength the workability of the specimen increased after austempered condition as the workability of the material depends not only on the ductility but also on the strength .Therefore the austempered steel has a better workability when compared with annealed steel.

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