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The influence of forge reduction ratio on the tensile properties of AISI 321 Stainless steel

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Abstract — An attempt has been made to investigate the influence of forge reduction ratio on tensile properties such as elongation, reduction in area, tensile strength and yield strength of AISI 321 Stainless Steel alloys under different forging reduction ratios ranging from 1:1 to 15:1.

The forging process is carried out at different forge reduction ratio and the change in mechanical properties with respect to reduction ratio is measured to optimize the material property.

Index Terms— Forge reduction ratio, tensile properties, AISI 321 Stainless Steel and microstructure.

I. Introduction

AISI 321 Stainless steel is mainly used for the production of Aircraft parts, Chemical Processing Equipment, Jet Engine Parts etc. AISI 321 is a stabilized Austenitic stainless steel which offers as its main advantage an excellent resistance to intergranular corrosion following exposure to temperatures in the chromium carbide precipitation range from 427 to 816° C. Type 321 is stabilized against chromium carbide formation by the addition of titanium.[3] While in the production of certain parts it was observed that the ductility and elongation of the material is poor whose result was obtained from laboratory test after completion of all forging and heat treatment process.

Forging is defined as a metal working process in which the useful shape of work piece is obtained in solid state by compressive forces applied through the use of dies and tools. Forging process is accomplished by hammering or pressing the metal. The major adjustable parameters in forging are reduction ratio and forging temperature. This project concentrates on analyzing these parameters and to determine how they depend on the mechanical properties of AISI 321 Stainless steel. Attention is also directed toward identifying micro- structural differences which may account for a change in mechanical property behavior. [6]

The present research investigates the variation of grain structure and mechanical properties when AISI 321 Stainless steel alloy is subjected to different forge reduction ratios.

II. METHODS AND MATERIAL

The characterization of the specimen was carried out in spectrometer (German made, foundry master) connected with Wasag Lab Software is shown in figure 1. The major constituents of AISI 321 Stainless steel alloy are identified.

Figure 1: Spectrometer

Figure 2: Specimen machined as per standard

The open forging of the alloy was done with a 1Ton clear space hammer. The present work used an as-cast AISI 321 Stainless Steel disc of 200 mm in diameter and 107 mm in length. Forging was undertaken in a way which enabled mechanical property evaluation at a number of different forging reduction ratios ranging from 1:1 (i.e. as-cast) to 15:1

The heat treatment of the forged alloy was done in a pit furnace with advanced electronic temperature controller attached with digital timer as show in figure 2. The forged Specimen is preheated to 700℃, soaked for 1 hour. Then again the temperature is raised to 1050℃, soaked for 3 hours and water quenched for 30 seconds. The computer based active closed loop temperature control system of the furnace maintains the temperature uniformity of the chamber and assures isolation of the material from the surroundings.

Figure 3: Electric Pit Type Furnace

An extensive study on significant mechanical properties - Hardness, Tensile stress, and Grain structure analysis of AISI 321 Stainless steel alloy were conducted at all the different forge reduction ratios.

The mechanical properties namely proof stress, tensile strength and elongation of the specimen after annealing was investigated in the Universal Testing Machine (UTM) having capacity 400 KN as shown in figure 3. The dial gauge readings obtained from the extensometer mounted on the specimen was used to find the actual elongation and the corresponding strain induced in the specimen under different loading conditions in the experiment. [2]

Figure 4: Universal Testing Machine

Yield point of the AISI 321 Stainless steel alloy was found to be difficult to capture in the tensile test, hence corresponding proof stress was evaluated at 0.2% of the gauge length from the line of proportionality. [1] The stress-strain graphs for the different annealed conditions were plotted in Graph 1.

The hardness of all the specimens was tested in the Brinell hardness tester. A steel ball indenter of diameter 10 mm under 1000 kg force is applied for 10 seconds. The diameter of the indentation,'d' was measured by optical microscope. The corresponding Brinell hardness number was calculated using the following expression.

$$\text{BHN} = \frac{P}{\left(\frac{\pi D}{2}\right) \times \left(D - \sqrt{D^2 - d^2}\right)}$$

The specimen is then prepared for microstructure analysis. Alloy was cut and the distorted material was removed by wet grinding followed by fine polishing with the aid of 24 micron abrasive powder.[5] Using optical microscope (200X), the grain structure of the AISI 321 Stainless steel alloy at different forge reduction ratios were explored in the present work.

III. RESULTS AND DISCUSSIONS

The influence of forge reduction ratio on various mechanical properties was quantified in terms of tensile strength, reduction area, elongation and hardness of the AISI 321 Stainless steel specimen. Their performance variations are shown in figure 5(i), 5(ii) and 5(iii) respectively.

The results obtained from 200X optical microscope which exhibit the grain sizes are shown in figure 6(i), 6(ii) and 6(iii) respectively.

The small variation in anisotropy ratio over the entire hot working range is illustrated in Figure 7. It shows that there was little deterioration in transverse reduction of area values even with forging reductions approaching 15:1.

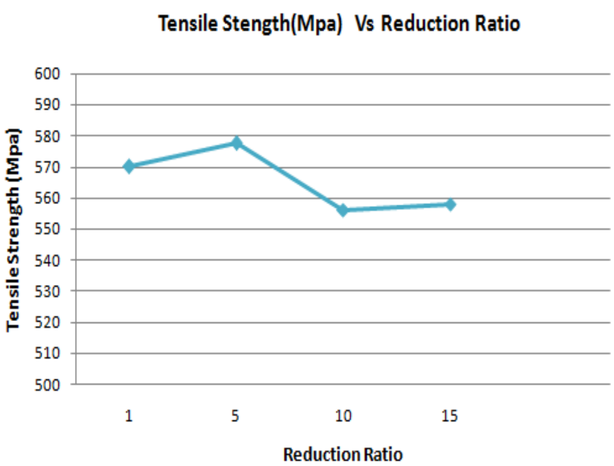

Figure 5(i)

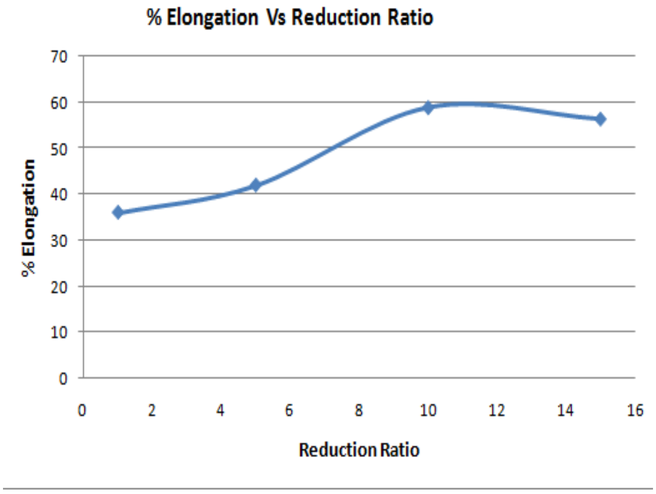

Figure 5(ii)

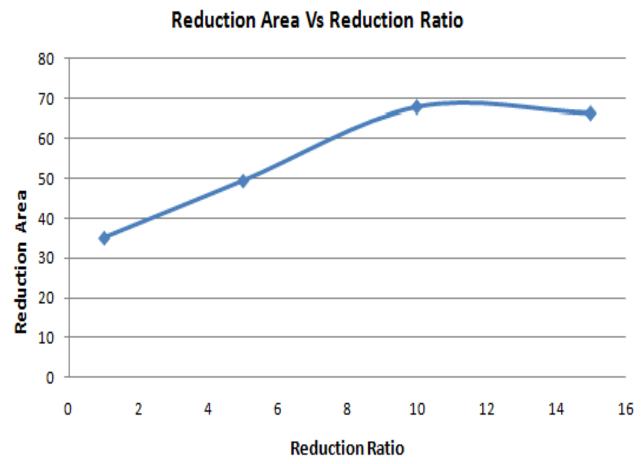

Figure 5(iii)

Figure 5: The variation of mechanical properties with different Reduction ratio (Transverse direction)

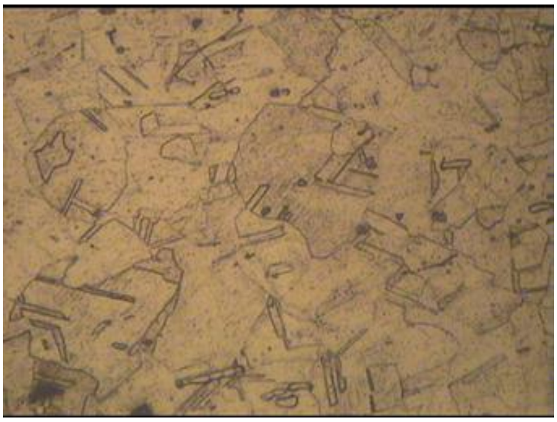

Figure 6 (i)

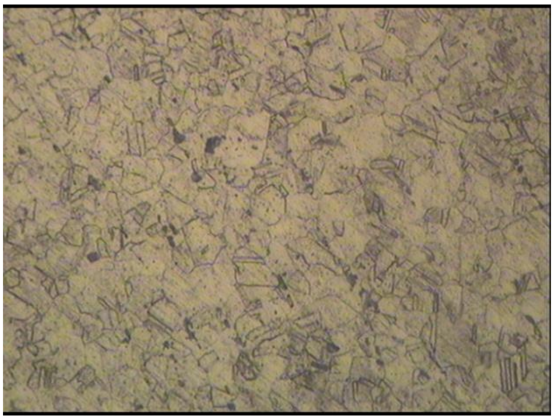

Figure 6 (ii)

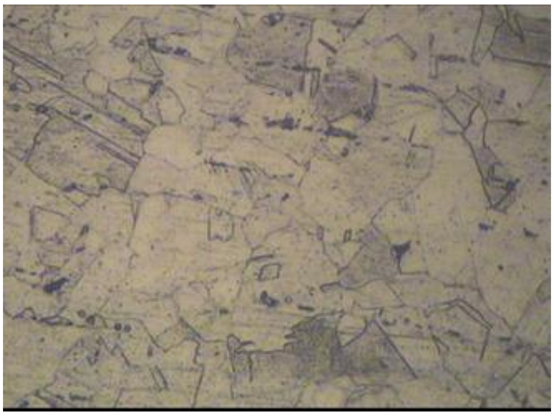

Figure 6 (iii)

Figure 6: The grain structure of specimens at 200X magnification. (Longitudinal direction)

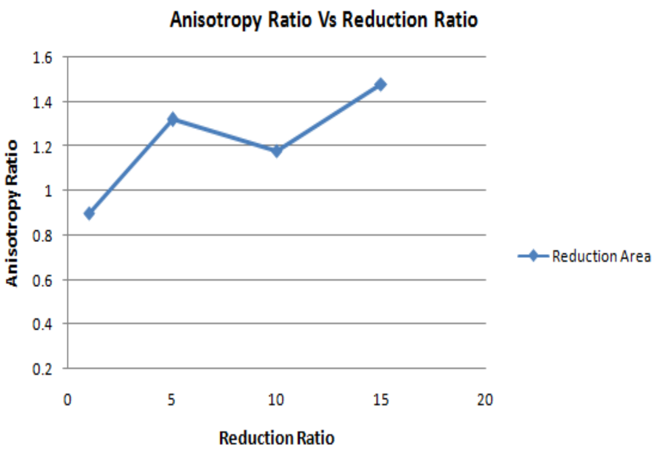

Figure 7: Anisotropy ratio Vs Reduction ratio

IV. CONCLUSIONS

The reduction area and Elongation increases as the forge reduction ratio increase in both transverse and longitudinal direction. Hence the tensile properties improve significantly when the forge reduction ratio is increased.

The optimum values of mechanical properties were obtained when reduction ratio was above 5:1.

The grains become slightly finer with an increase in forge reduction ratio.

Little mechanical property anisotropy was observed with this AISI 321 Stainless steel alloy.

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NOMENCLATURE

AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
UTM	Universal Testing Machine

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