Cooling rate and Micro-structural Characteristic evaluation of HSLA steel

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Abstract. In recent years HSLA steel replacing the application of common heat treated grades of steel. The precipitation of carbon-nitrides and carbides are main strengthening mechanism of micro alloy steel. The mechanical properties such as impact strength and toughness of micro alloy steel is enhanced without reducing ductility. This work focus on hot compression test on HSLA steel, which has been performed within the thermo mechanical simulator. The characteristic evaluation of deformed alloy conducted by utilizing optical, scanning and transmission electron microscopy for understanding precipitation nature of micro-alloy steel. Microstructure behaviour are also observed under variation of cooling pace.

Keywords: HSLA, Micro alloy, SEM, Cooling rate, Micro structure

1. Introduction

HSLA steels consist maximum 0.15 % of alloying element and the standard alloying elements are vanadium niobium and titanium. The percentage of micro alloying element is in the range of 0.1 to 0.15 of weight percent. These alloying element refine the grain size and produce the stable carbide and carbonitrides. Aluminium can also use as micro alloy element as it forms the stable AlN grain size refinement and boron for hardenability, and elements residual from steelmaking, may of course also present in steels in small amounts, but such elements and their effects are generally considered to be outside of micro alloying technology. Many applications for structures, automotive machine and vehicle parts require high strength and good fatigue resistance. Traditionally, steels for these applications have been produced by forging and then heat treating to produce martensitic microstructures. The hardened microstructures are then process annealed, at low temperatures and the harder phases are removed from microstructure consist of ferrite and pearlite precipitation strengthened by carbonitrides precipitate dispersions [1].
The experiments therefore consisted of reheating the specimens at 1000°C, holding the same for 1 hour and hot rolling to about 30% thickness reduction. After deformation, specimens were immediately cooled using still air, forced air, salt bath, oil and water media to study the effect of cooling rate on the microstructure and mechanical properties on this steel. It is observed that the final microstructures are greatly influenced by cooling rate. In the still and forced air cooled conditions, the microstructures are mainly consisted of ferrite and pearlite. At very high cooling rates, (cooled in water or oil), the microstructure is composed of mainly martensite. The strength and hardness values of the specimen increase and elongation decreases with increase in the cooling rate. It is noted that the fracture surface changes from ductile to brittle fracture with an increase in cooling rate [2-3].

Micro alloyed steels that have been used for efficient transportation of oil and gas at higher pressure and transmission rate over long distances. These pipeline steels have high strength and toughness values at extremely low temperatures. The HSLA steels are the high strength low-alloy (HSLA) steels and most have been marked under proprietary names. The applications of these steels are based on dominant consideration of the efficiency to cost ratio, profitability due to weight and wall thickness reduction, better yield strength, durability, corrosion resistance and weldability. These steels are used for a variety of applications, including cars, pressure vessels, pipe line, ships and offshore platforms [4].

The demand for stronger, tougher and weld able structural steel has been witnessed tremendous interest of the industry to go for a continuous improvement and adaptation of hot rolling process. Firstly, the higher strengths in steel were achieved by increasing the amount of carbon in the composition during 1900’s. Then, in the 1940’s, the amount of carbon was decreased while the level of Mn was increased in order to improve weld ability and fracture resistance; vanadium, niobium, molybdenum and titanium were also added to increase the strength. Recrystallization mechanisms of austenite phase play an important role to obtain required microstructure with improved physical properties. As steel is deformed, the internal energy increases through the accumulation of dislocation and simultaneously various softening processes occur that reduces the internal energy of the deformed steel [5-6].

The recovery is the process of enhanced atomic diffusion accompanied with atomic rearrangement to relieve internal energy without the application of external stress. Even after the recovery is completed, the grains are in high energy state. The energy stored in deformed grains, post recovery, is utilized for recrystallization processes [7]. Many other researcher have also working on same area [8-13]

2. Experimental Process

The experiments were conducted to enhance our understanding on the effect of key process parameters to obtained relevant microstructural features and desired mechanical properties for the development of the HSLA steel. The main objectives of these experiments are to study the effect of cooling rate and thermo-mechanical processing parameters on the microstructure and mechanical properties of micro alloyed steel leading to HSLA steel grade steel properties.

3. Materials used

The HSLA steel plate of 8mm, which served as the starting material for the experiments in this study. The chemical composition of this material is shown in Table-01. Pictorial view of the HSLA steel, Small pieces of the dimension 10 mm×10 mm×8 mm were machined from the material for further studies. The specimens were austenitized at 1000°C for varying time period in order to see the effect of heating time on the prior austenite grain size. Specimens were held at 1000°C for 1 h and 2 h, followed by water quenching so as to retain the state of austenite [14-15]. The chemical composition of alloy is given in Table-01

Table 1. Chemical composition of Alloy:-
### 3.1 Hot rolling experiments

Hot rolling experiments were carried out to study the effect of cooling rate on the microstructure of HSLA steel, after hot deformation. Plate of thickness 20 mm and length 160 mm was cut from the HSLA steel plate. The plate was heated at 1000°C for 45 minutes followed by hot rolling deformation using two as well as four high rolling mill to reduce the thickness of specimen from initial thickness of ~8 mm to ~6 mm and then cooled to room temperature [16].

All specimens, each of breadth 120 mm were cut from the 20 mm thick hot rolled plate. In this set of experiments, specimens were reheated to the temperature of 1000°C. After holding at this temperature for 1 h, each specimen was hot rolled to about 30% thickness reduction. After deformation, specimens were immediately cooled in different cooling media that was supposed to give rise to different microstructural features and mechanical properties. Rolled specimens were cooled using still air, forced air, oil bath, salt bath and water to study the effect of cooling rate on the microstructure and mechanical properties on this steel [17-18].

### 4. Results and Discussion

The results of the experimental investigations are presented in this section. The results obtained for the microstructure evolution and mechanical properties, developed under different thermo-mechanical processing conditions, have been discussed, in detail, of these are discussed in the following sections.

#### 4.1 Microstructure

Optical microstructure is shown in Fig.01 depicts the cross-sectional optical micrograph of the HSLA steel material along the thickness direction. The micrograph was taken from the centre of the specimen. Optical micrograph of the as received HSLA steel material reveals, predominantly ferrite with some amount of pearlite. It is also shows the bended structure as well as polygonal ferrite Figure 1 shows the cross sectional SEM micrographs taken from central region of the specimen. Microstructure shows acicular ferrite and bended micro-graph it results due to the thermo-mechanical processing of alloy [19].

| C  | Mn | Si  | Nb  | N (ppm) |
|----|----|-----|-----|---------|
| 0.22 | 1.48 | 0.40 | 0.085 | 100     |
4.2 Reheating of starting material

As already described in the previously the reheating of the above particular alloy done at 1000°C for a period of 10 min, in this set of experiments the specimens were austenitised at 1000°C for varying time period in order to see the effect of heating time on the prior austenite grain size. In the microstructure, no ferrite is observed for all the specimen only the retained austenite and martensitic structure is present in the alloy [20]; and immediate water quenching results in a fully martensitic structure. Polygonal ferrite disappeared from the micro-structure. Microstructures also reveal the presence of coarser martensite, this coarser martensite work as the nucleation site for the cracks in the specimen held for 1 h in comparison to the specimen reheated at 1000°C for 1 hour. As shown in fig.02. SEM images of reheat alloy are shown in Fig-03, it consist the very fine peralite and lathlike structure identified as martensite, these martensitic structure results due to the faster cooling. The size of martensitic blocks or lathes are important factor in the development of nucleation of retained austenite [21-26]. The size of martensitic lathe also depend upon the austenite grain size prior to transformation. The grain size increased with increasing reheat temperature due to the formation of coarser austenite and decreasing deformation for 1000 °C rolling deformation. The ferrite grain size observed after austenitisation at 1100 °C and rolling at 700–900 °C was in the range of 6–9µm.
4.3 Influence of cooling rate

In this set of experiments, specimens were reheated to the temperature of 1000°C. After holding at this temperature for 1 h, each specimen was hot rolled to about 30% thickness reduction. After deformation, specimens were immediately cooled in different cooling media to reveal different microstructural features and mechanical properties of the specimens [27-28]. The microstructures are mainly consisted of ferrite and pearlite. It is clear that increase in cooling rate leads to finer ferrite grain sizes, shows the optical micrograph of hot rolled specimen quenched in a salt bath at 600°C for 30 minutes. The microstructure is characterized by equi-axed polygonal ferrite grains with smooth boundaries and with some fraction of pearlite Fig. 04. At very high cooling rates, (cooled in water or oil), the austenite transform to martensite. In the oil quenched condition the microstructure is composed of mainly tempered martensite [29], whereas in water cooled conditions the microstructure is essentially quenched martensite.
5. Conclusion

- Acicular ferrite microstructure increases the precipitation density.
- Reheating improve the dispersion of precipitate.
- Optimum cooling rate refine the microstructure
- Grain refinement cause increase in strength and mechanical properties.
- The mechanical property of HSLA is satisfactory compared to the conventional steel. The yield strength of micro alloy steel is noticed up to 600MPa, for the controlled rolled steel.

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