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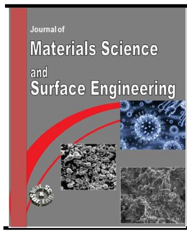

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Precipitation of Copper and Grain Refinement in Low Carbon Steel in Hot Rolling

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Abstract

In present investigation, 0.05C-1.52Cu-1.45Mn steel were subjected to multi-pass hot rolling at temperatures 800°C and 850°C in order to studied the hot rolling characteristics of ferrite. It is found that disc-shaped copper is precipitated along grain boundary of ferrite. At lower rolling temperature austenite is transformed to diffusional decompositional product. The ferrite grains of size around 10 microns were formed. However, when the same steel is rolled at higher temperature; ferrite of grain size around 2-5 microns appeared is formed in the micro-structure. It is due to inhibition of grain boundary movement by copper precipitate. The size of copper precipitates was found to be around 20nm in size.

Introduction

Hot rolling envisages ferrite grain refinement in steel which leads to increase the strength and improve its toughness. Hot rolling is the process in which steel is finish rolled in the non-recrystallization region. The austenite grains are flattened and huge dislocations in the form of deformation bands are created. These deformation bands act the intra-granular nucleation of ferrite. Increasing the cooling rate after rolling plays two important roles; first it leads to greater under-cooling and thereby enables to achieve a higher nucleation density; second by as the steel cools, the growth rate of ferrite is reduced; both these events make ferrite grains finer. This approach has enabled the production of steel with grain size in the range of 5-10 µm. Microstructure control can be affected by means of suitable design of rolling schedules, so as to be able to produce fine ferrite in low carbon steels [1-6]. Low carbon steel imparts malleability therefore it is most common steel which is used in sheet metal works. It is neither extremely brittle nor ductile because of its intermittent carbon content. However low carbon contents also improves toughness and weldability but its strength is decreases. The addition of micro alloying elements raises the mechanical strength of steel by precipitation hardening processes; also these precipitates can exerts a pinning effect on re-crystallized grains evolving during annealing therefore re-crystallization becomes a sluggish process. Micro-alloying with Nb/Ti is also known to insure extra refinement in low carbon steel. When low carbon steel mechanically worked in two phase field, dynamic softening takes place. Nb micro-alloyed steel has beneficial effects on strength; however it also retards re-crystallization of austenite during hot rolling. It is found that Nb treated steel sheet of thickness less than approximately 3 mm can be easily controlled rolled. Addition of copper to steel leads to improves the microstructure of low carbon steel by precipitation strengthening. It is also found that addition of copper up to 0.8% significantly improved the strength through precipitation hardening [7]. Hornbogen et. al in 1960 studied copper clustering, its precipitation and coarsening behavior and its effect on microstructure and strength [8-10]. The affect of micro-alloying elements is not constant along the thickness of strip due to segregation. During solidification, segregation of micro-alloying elements takes place at the center of strip however carbon generally segregated at the surface of strip. The austenite size obtained in the last stand of hot rolling affects significantly the final ferrite grain size. In the present work an attempt is made to study the effect of copper precipitation and grain refinement of steel in hot rolling. A Cu based steel is hot rolled at two temperatures 800 °C and 850 °C after holding at these temperatures for 10 minutes.; its characterization were done by scanning electron microscopy, transmission electron microscopy and energy-dispersive X-ray spectroscopy . It is found that Cu precipitates around the grain boundaries and refine the ferrite grain size to 5µm.

Materials and Methods

The material under investigation is 0.05C-1.52Cu-1.45Mn steel. The chemical composition is shown in Table 1. The specimens were subjected to hot rolling at 800 ^{o}C and 850 ^{o}C with holding time of 10 minutes (Fig. 1). The SEM images with EDX and TEM images were taken for hot rolling characterization.

Table 1: Chemical Composition of Steel

Element	C	Si	Mn	P	S	Cu	B
Wt %	0.05	0.13	1.45	0.012	0.01	1.52	0.001

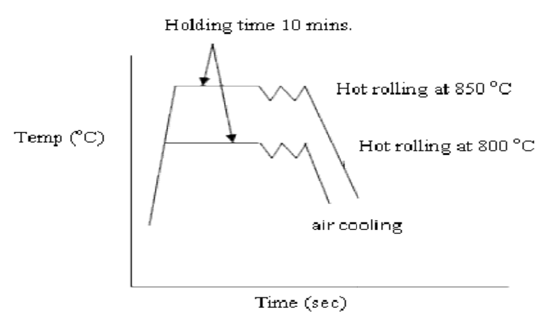

Figure 1: Hot rolling of steel

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Results and Discussion

SEM characteristics when steel is rolled at 800°C

When Cu-B steel is rolled at 800°C followed by air cooling; the microstructure observed in FESEM provides evidence of presence of some pearlite; this is indicative of the fact that holding at this temperature prior to rolling has led to transformation of austenite to diffusional decomposition products.(fig.2 and fig.3).

SEM characteristics when steel is rolled at 850°C

When the same steel is rolled at higher temperature 850°C; warm worked ferrite of grain size less than 2-3 micron appears to have formed in the micro-structure Fig.4 and Fig.5. It appears from Fig.5 that there are few warm worked grains of size 1 micron; however some boundaries decorating the prior austenite grains of larger size are also noticed in the same photograph. On comparison of results with the steel rolled at 800°C it appears that warm worked ferrite is formed due to rolling at higher temperature. It is also appears that holding for ten minutes at lower rolling temperature 800°C tends to effect austenite transformation prior to onset of deformation.

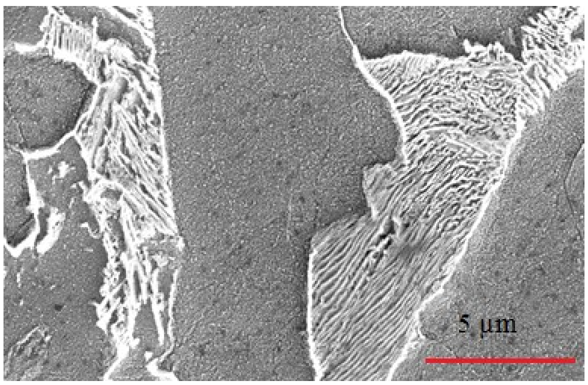

Figure 2: SEM image indicating formation of perlite

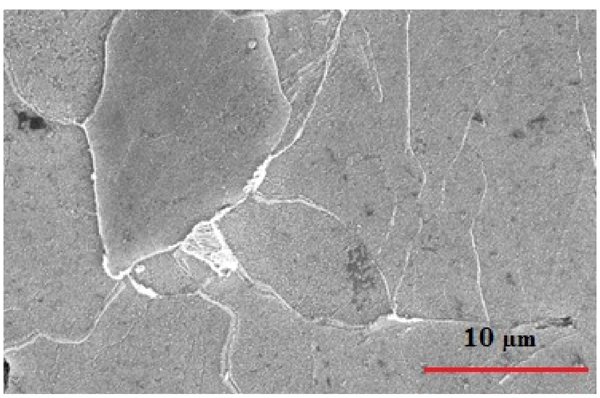

Figure 3: SEM image when steel is rolled at 800°C

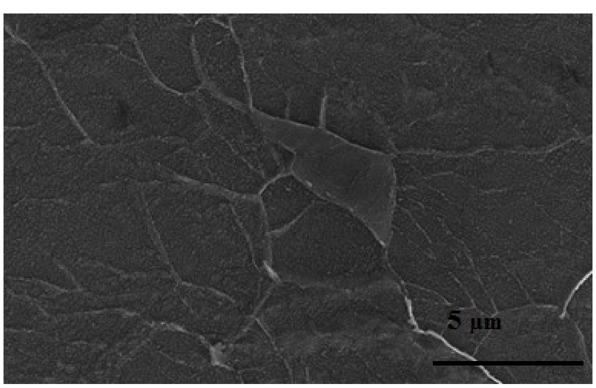

Figure 4: SEM image when steel is rolled at 850°C

TEM characteristics when steel is rolled at 800°C

When rolled at 800°C, shows high angle grain boundary with sub-grains delineated clearly; the sub-grains are found to be dislocation free as shown in fig.6. The precipitates are clearly seen in fig.7 and the fig.8 results confirm that they are of copper. It is further noted that the copper precipitates formed here is of 20 nm size. Similar observation of the existence of fine precipitates at the grain boundaries can be made in Fig.9.

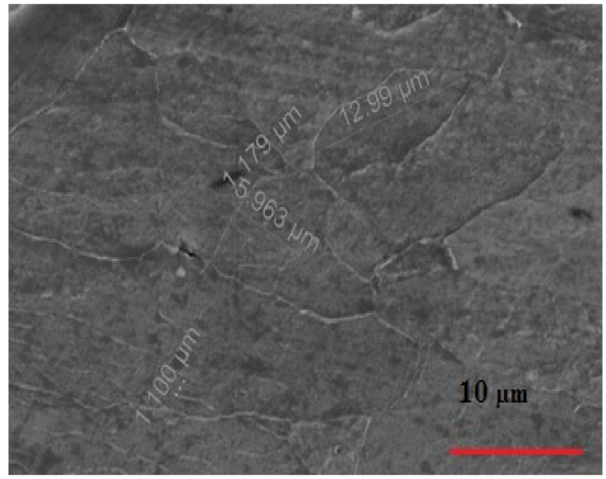

Figure 5: SEM image when steel is rolled at 850°C

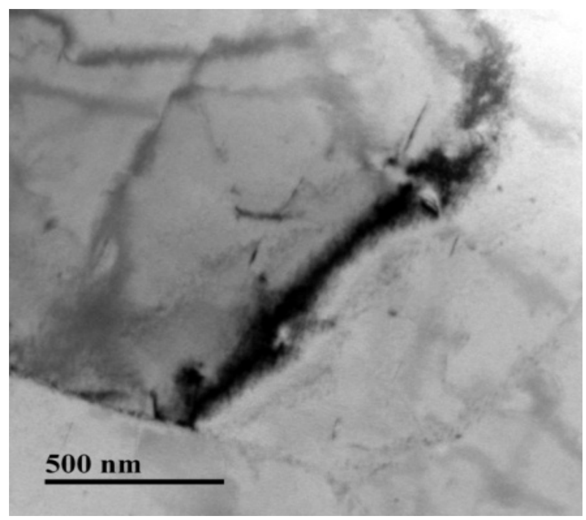

Figure 6: TEM image showing high angle grain boundary

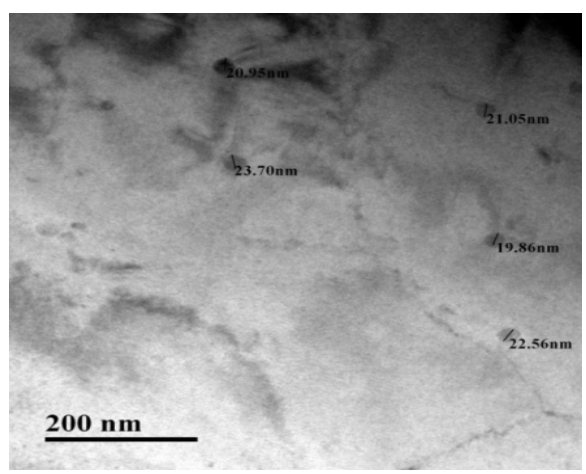

Figure 7: TEM image showing precipitates of copper of size 20nm

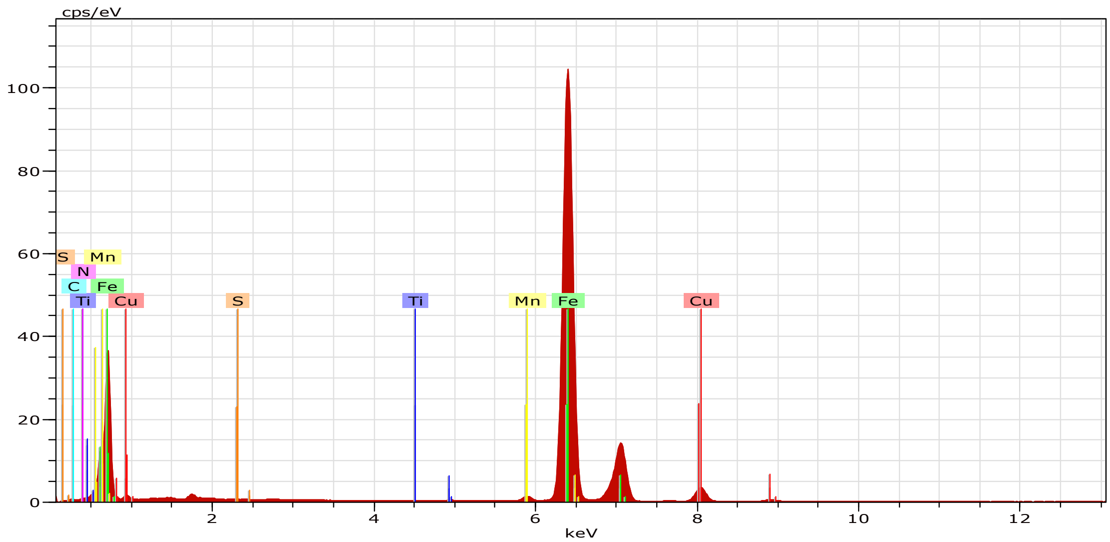

Figure 8: EDX when rolled at 850°C

TEM characteristics when steel is rolled at 850°C

When the rolling is done at a higher temperature the ferrite grain/sub-grain relatively free of dislocations formed are found to be of size 200nm (Fig.10). The precipitates of copper are formed at the grain boundaries. The high resolution image in Fig.11 clearly shows that copper is precipitated at dislocations separating two grain areas. EDX of Fig.11 records the appearance of copper precipitates as shown in Fig.12

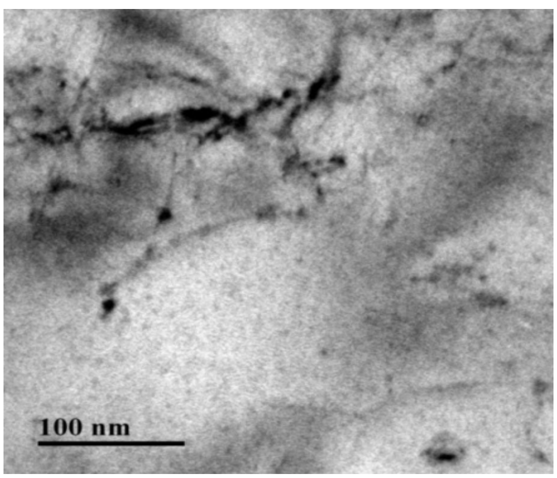

Figure 9: TEM image showing precipitates at the grain boundaries

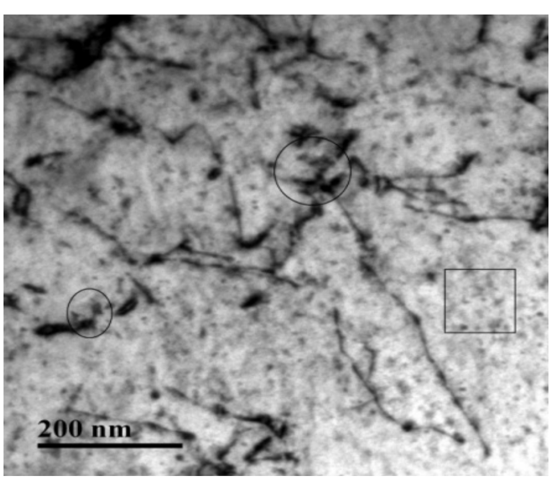

Figure 10: TEM image showing ferrite grains/sub-grains

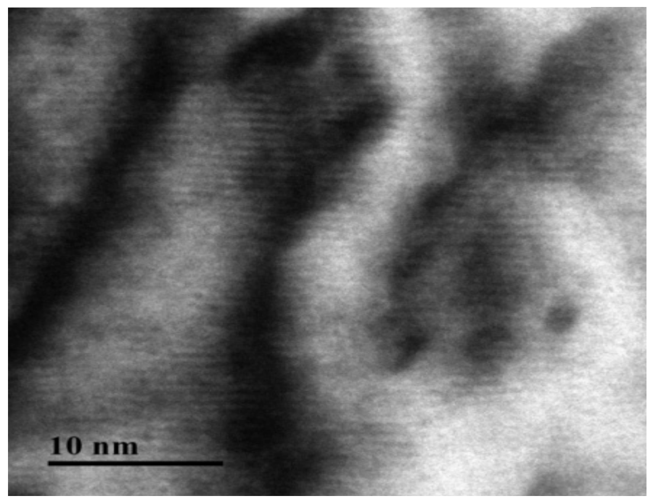

Figure 11: TEM image showing copper is precipitated at dislocations separating two grain areas

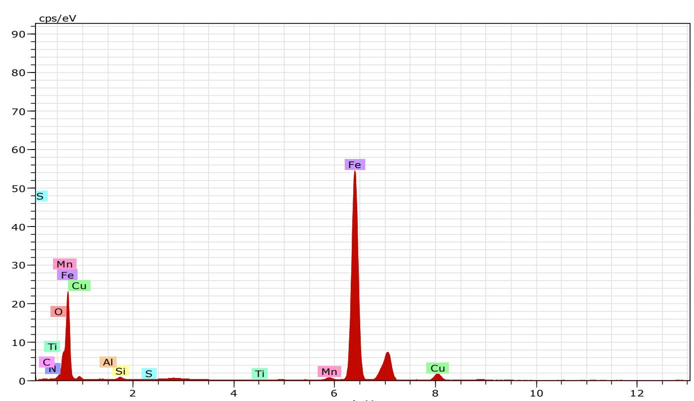

Figure 12: EDX results of Cu-rolled at 850 ^{0}C

Conclusions

Ferrite grain of size 1-4 µm is formed when rolling at higher temperature It is also found that copper is precipitated along grain boundaries of ferrite The size of copper precipitate is of about 20nm. This copper precipitate can inhibit the grain boundaries movements; hence ultrafine ferrite can form. These will leads to better strength as the grain size is decreases.

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