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Microstructure and Mechanical Properties of IF-Steel Processed by Thermo-mechanical Controlled Rolling and Multi Axial Forging

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Abstract—*In recent years, use of interstitial free (IF) steels in the automobile sectors increases due to their excellent deep drawing ability, high strength to weight ratio and excellent toughness. Demand of improvement of the existing strength is increased day by day to enhance the performance of the components. Strengthening of the steels without losing their ductility is the key thrust of the research to meet the present challenges. Thermomechanical treatment with controlled cooling is one of the key processing methods by which the strength of the IF steels can be improved. Grain refinement is one of the possibilities to increase the strength without much impairing the ductility. In the present study, ultra-low carbon (0.005%) Nb-Ti IF steel (supplied by TATA Steels) has been investigated to improve mechanical properties through thermo-mechanical processing using multi-axial forging (MAF) and controlled hot rolling technique followed by different controlled cooling rates. Samples with dimensions 30 mm × 24.5 mm ×20 mm (maintained the ratio 1.5:1.22:1) and 40mm×25mm×10 mm were cut from the as-cast sample to deform through MAF and rolling, respectively. The cut out samples were annealed at 1200°C for 1h for its homogenization before deformation. Gleeble-3800 thermo-mechanical simulator was used to obtain dilatometric curves from which T_{nr} (1047°C, γ-recrystallization stop temperature during deformation), Ar_3 (782°C, temperature at which ferrite begins to form) were determined. On the basis of the critical temperatures, multi-axial forging was performed maintaining temperatures in 3 different regions i.e. in γ-recrystallization region (at T_{nr}+50°C) during deformation, in austenitic−ferrite transition region (at 780°C, Ar_3 region, also called γ-nonrecrystallization region) and pure ferrite region at 650°C (i.e. at below Ar_3). Deformation by rolling was performed through multi-pass reduction and thickness reduction was maintained at ~4% in each pass. Total reduction in area was ~34%, which is equivalent to 0.4 true strain. In between in each pass, the samples were heated in furnace to maintain a constant temperature. Whereas, in MAF the sample was turned to 90° after each pass and the next pass was given to the longest dimension. Total true strain per cycle (i.e. after 3 passes) was 1.2 ($\Delta\varepsilon$ = 0.4*3). Fig. 1 shows the schematic diagram of multi axial forging technique employed in this work. In this work up to 5 cycles or 15 MAF strain steps (total equivalent true strain $\Sigma\Delta\varepsilon$=6) were employed at three different temperature regions and then air cooled.*

The microstructural features were investigated by optical microscopy (OM) and fractography by scanning electron microscopy (SEM). Mechanical properties were studied by tensile and Charpy impact test and Vickers hardness measurement. It is found that both yield strength (YS) and ultimate tensile strength (UTM) of the multi-axially forged specimen are significantly improved without much impairing the ductility, especially when forged in pure $\alpha-ferrite$ region. The best combination of YS (601 MPa), UTM (627 Mpa) and ductility (23%) was obtained when the specimens were forged of $\alpha-ferrite$ phase region (660°C). The enhanced YS (601 MPa) is found to be more than 3 times higher and UTM is more than 2 times larger than that of the cast sample (YS = 196 MPa, UTM = 280 MPa and ductility = 28%).

The improvement in the mechanical properties with high ductility can been enlightened with the presence of finer grains, large accumulated strain, formation of subgrains and homogeneous distribution of ultrafine NbC and TiC precipitates within the ferrites.

Keywords: *IF steel; Thermo-mechanical simulation; Multi-axial forging; Controlled rolling; Mechanical properties; Fractography.*

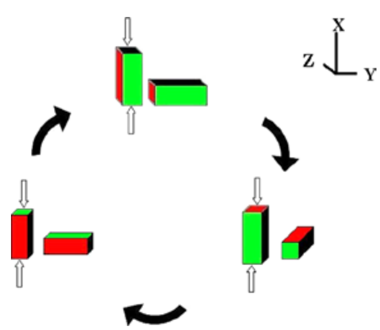

Fig. 1: Multi axial forging technique employed in this work.