ABSTRACT

The objectives of the present investigation are to optimize processing conditions to develop ultrafine-grained (UFG) low carbon steel through equal-channel angular pressing(ECAP) and post processing by cold rolling and cryorolling to further grain refinement to obtain ultra high strength in the material. Another objective is to regain the ductility in UFG low carbon steel with maintaining high strength through developing bimodal grain size distribution of ultrafine grains and micron-sized grains by suitable thermal treatments of UFG low carbon steel. Finally, correlations among microstructure, texture and mechanical properties will be established.

Low carbon (0.8wt%C) steel work pieces of 15 mm diameter is deformed through an ECAP die upto an equivalent strain, ε_{vm} =16.8 adopting route Bc at room temperature. The ECAPed material is further deformed by coldrolling upto 80% reduction in area and cryorolling at -50°C upto 75% reduction in area followed by flash annealing at various temperatures (475-675°C). Microstructures are examined by optical microscopy, scanning electron microscopy, transmission electron microscopy (TEM) and electron back scattered diffraction (EBSD) from the bulk specimens. EBSD Data is analysed for misorientation, grain boundary fraction and microtexture. Bulk texture, dislocation density and elastic stored energy are measured from X-ray diffraction (XRD) study. Mechanical properties are evaluated by microhardness measurement, tensile testing, and fractography.

Ultrafine-grained structure of average grain size of 0.2µm with high angle of misorientation, ~40°, has been achieved in the coarse-grained low carbon steel by by ECAP at ε_{vm}=16.8 at room temperature. The rate of refinement is high at initial stages of deformation but it decreases with the amount of imposed strain. At initial stages of deformation most of the grain boundaries are of a low angle of misorientation. Lowest level of low angle grain boundary

fraction is < 20% at ε_{vm}=16.8. Defect density increases with imposed strain and reaches a maximum value at intermediate strain but decreases to lower level at higher strain.

On ECAP the grains get elongated at the initial stage of deformation (ε_{vm}=0.6) and get subdivided into bands. At intermediate strain (ε_{vm}=1.8) a cellular structure develops within the bands due to the rearrangement of dislocations. At high strain (ε_{vm}=9-12), bands get further elongated and form ribbon grains. These ribbon grains get broken down partially to near-equiexed grains due to the intersection of bands of which they are constituents. At large strain (ε_{vm}=16.8) cellular structures converted into granular one. In the low carbon steel pearlitic cementite starts dissolving at equivalent strain as low as 6 and the lamellae are partially broken. The dissolution of cementite continues with strain but complete dissolution could not be achieved within the equivalent strain of 16.8.

The material is strongly textured upon ECAP with imposed strain. New components are developed at different strain levels. At low to intermediate strain level F_θ, J_θ, $\bar{J}_{\theta,}$ $D_{1\theta,}$ and F_θ texture components typical of pure shear are formed. At high strain level new component E_θ is formed. The positions of components are nevertheless deviated from their ideal position. The deviation decreases with the dissolution of cementite in to ferrite matrix.

Strength and hardness increase rapidly at early stage of deformation due to rapid rate of grain refinement and increase in defect density but the rate of strengthening and hardening decreases with strain as refinement rate and dislocation density decrease. An ultrahigh level of ultimate tensile strength greater than 1000 MPa has been achieved at ε_{vm} = 16.8 but failure takes place by brittle fracture at high strain level ε_{vm}=16.8.

The ECAPed low carbon steel of ultrafine-grain structure is further deformed to greater than 75% reduction in area by cold rolling or cryorolling and the material has been refined to ~100 nm.

Bimodal grain size distribution consisting of ultrafine grains and micron-size grains of ferrite are obtained by post ECAP deformation and followed by optimized thermal treatment where ultrafine grains offers high resistance to deformation, i.e. high strength but micron sized grains with development of γ-fibre components add ductility for the material by changing the nature of failure from brittle to the ductile fracture of the ferrite phase.