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The effect of cryorolling on tensile strength and fracture toughness of 6063 Al-alloy.

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Abstract

In the present research work, 6063 Al alloy was cryprolled for different reduction for tensile test and fracture toughness test. 30%, 50%, 70% and 90% reduction were done for tensile measurement. 30, 50%, 70% and 80% reduction were carried out for fracture toughness test. The formation of precipitates and intermetallic compounds were characterized by XRD analysis. The micro structural examined were carried out by optical micro-scope and transmission electron microscope. Dimple rupture is characterized by cup like depressions that denote a ductile fracture in the tensile samples it was seen that quasi-cleavage is found in the fracture toughness samples. The cracks are formed at grain boundary triple points and it propagates along the grain boundry which means fracture occurs in a intergranular mode. The fracture toughness of 80% cryorolled is 65.8313 MPa √m.

Keywords: *Cryorolling, Tensile test, Fracture toughness.*

1. Introduction

Al-Mg-Si alloy are used for aerospace and structural components due to excellent strength to weight ratio, excellent thermal and electrical conductivity and excellent corrosion resistance and oxidation resistance. 6063 alloy are used in architectural, extrusion, window frames, door, shop fitting, irrigation tubing, road transport, rail transport and extreme sports equipment. Solubility in the solid state decreases with the decreasing temperature. When the super saturated solid solution is cooled from high temperature then it becomes unstable at low temperature. The free energy change occurs favours. The rejection of solute in the form of precipitate particles.

$$\alpha\ (SSSS) \rightarrow G.P\ zones \rightarrow \beta^{11} \rightarrow \beta^{1} \rightarrow \beta$$

G.P zones are generally spherical clusters which is coherent with matrix. β^{11} precipitates are fine needle shaped zones with monoclinic structure which is non coherent with matrix, β^{1} are rod shape precipitates which show hexagonal structure. Equilibrium phase β with FCC structure is stable at room temperature. There are few severe plastic deformation technique to get ultrafine grained structure:

(1) High pressure torsion (HPT)
(2) Equal channel angular pressing (ECAP)
(3) Accumulative roll bonding
(4) Cryorolling
(5) Cyclic extrusion compression (CEC)
(6) Repetitive corrugation and straightening (RCS)
(7) ECAP-confirm
(8) Incremental ECAP (I-ECAP)

6000 series alloy have lot of use, it is important to know their mechanical behaviour when exposed to different condition of load, strain rates and temperature and to be able to model their behaviour [6-8]. SPD (Severe plastic deformation) leads to highly interest in the last years due to interesting properties which can be achieved in bulk materials by SPD [5]. It is a method which is capable of producing fully dense and bulk submicrocrystalline and nanocrystalline materials. Grain refinement by SPD leads to improvement of mechanical microstructural and physical properties [9]. Among 6000 series,6063 alloy is most popular alloy. It provides good extrudability and a high quality of surface finish.

› Architectural and building products
› Electrical components and conduit
› Pipe and tube for irrigation systems
› Door and window frames
› Railings and furniture

Cryorolled 6063 alloy is used in aerospace. In the heat-treated condition, 6063 alloy has good resistance to general corrosion and stress corrosion cracking.

The intermetallic compound Mg_2Si is responsible for the hardening of this alloy[1-4]. When it is subjected to plastic deformation, the stored energy is dissipated in the form of heat and only two to ten percentage energy accumulated in the form of crystal defects. This energy is further dissipates in the form of migration and annihilation of defects and becomes thermodynamically stable. Usually cold working consists of resistance against deformation which results into loss of ductility. The elongated grains are present after plastic deformation. The purpose of homogenzing is given below:

- Reduction of the Mg and Si concentration gradients
- Dissolution of the Mg_2Si particles formed during solidification
- Fragmentation and spheroidization of the a-Al-Fe-Si
- Transformation of the β-Al-Fe-Si into α-AL-Fe-Si

Microsegregation of Mg and Si is quickly reduced at temperature in excess of 550^0 C which results into high diffusivity of Mg and Si in aluminium. The controlling step is the homogenizing process are the β-Al-Fe-Si to α-Al-Fe-Si transformation and the breaking up and spheroidization of the α-Al-Fe-Si phases,which is slow process.

2. Experimental

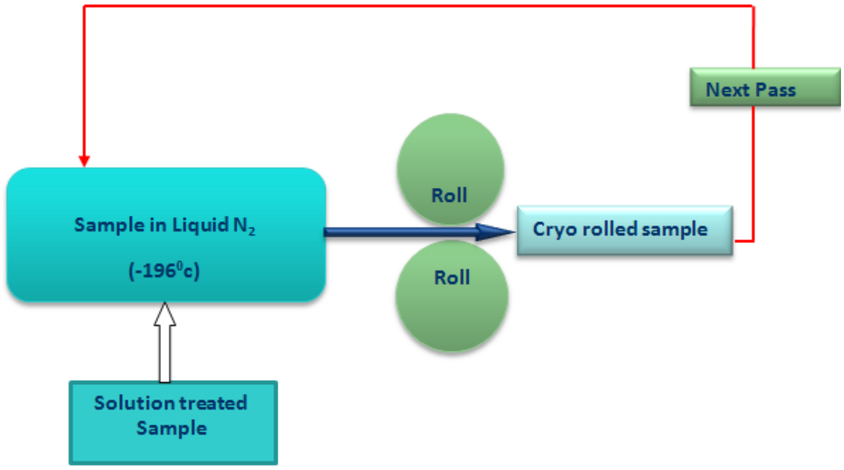
Materials are procured from HINDALCO,Renukoot having the following composition:

Table (1) Chemical composition of 6063 Al- alloy.

Mg	Si	Fe	Cu	Mn	Ti	Zn	Cr	others	Balance
0.3	0.45	0.06	0.016	0.013	0.03	0.001	0.1	0.1	Al

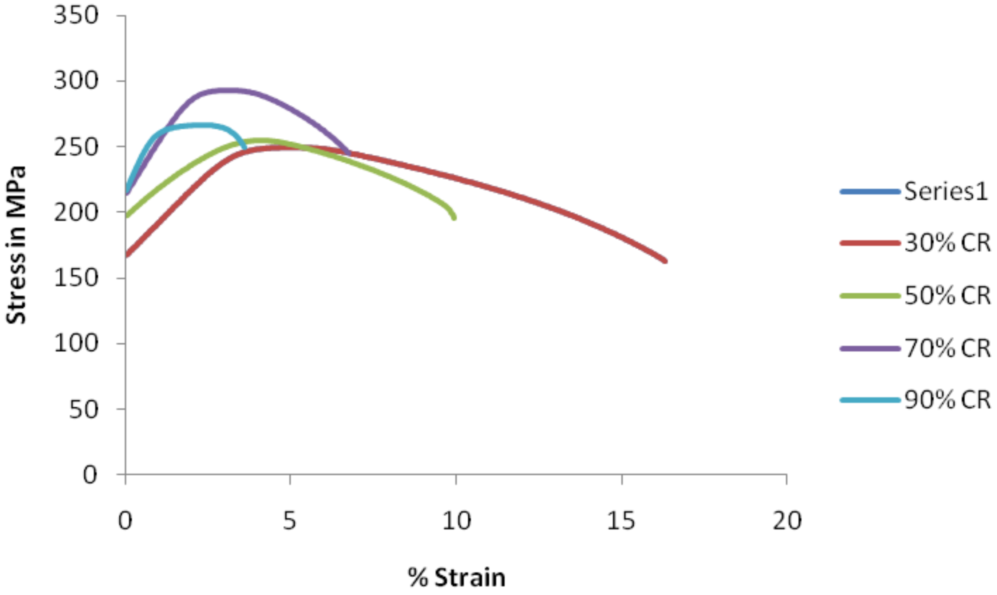
2.1. Cryorolling

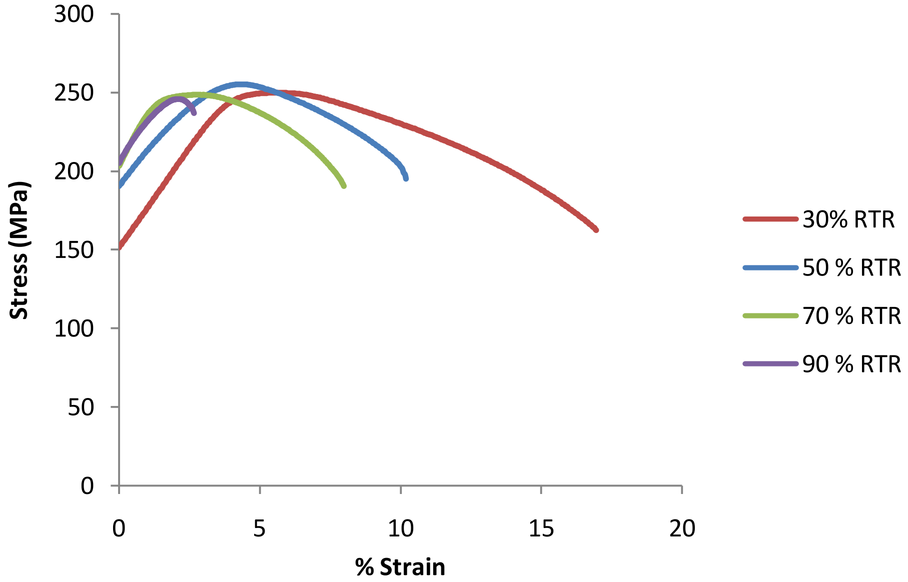
It is one of best technique to produce ultra fine grained Al alloy. Samples are immeresed in liquid nitrogen after each pass to suppressed dynamic recovery. The diameter of roller is 110mm and to reduce frictional heat between roller and sample, a low rolling speed of 8 revolutions per minute is used.0.2 mm reduction is given to the sample after soaking in liquid nitrogen for 30 minutes.



2.2 Tensile test

Tensile test specimen are prepared according to ASTM E-8 Subsize, having the gauge length 25mm and total length 100mm. Tensile test are carried out using a S-Series H25K-S Material testing machine at a constant crosshead speed with An initial strain rate of 5×10^{-4} S^{-1}.





2.3. Hardness

Samples are prepared after polishing on emery paper with Grit size 320,600,800 and 1000. After doing paper work, The sample were further polished on cloth. The applied load during the test is 5 Kgf and dwell time is 15 seconds.

2.4. Optical microscope

Samples were cut down into the dimension 10mm×10mm and corresponding thickness according to the cryorolling. The samples Were prepared on polishing with 320,600,800,1000, 1200 and 2000 Grit size. Finally samples were polished on the cloth with MgO Powder paste. ST and rolled samples were etched with the pollution reagent.

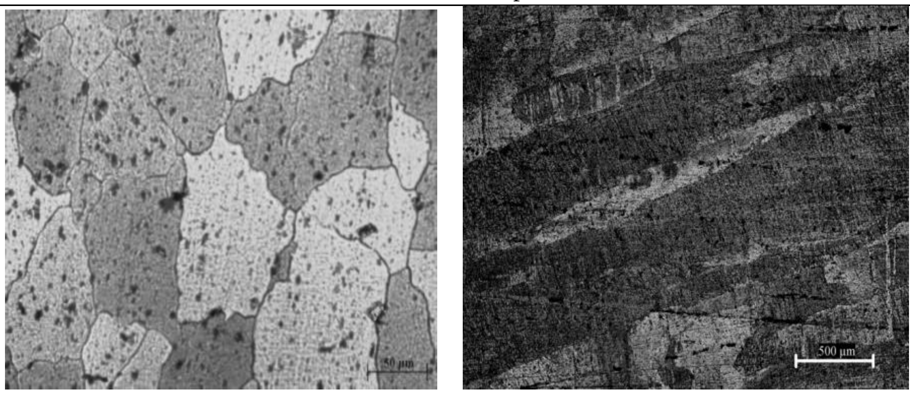
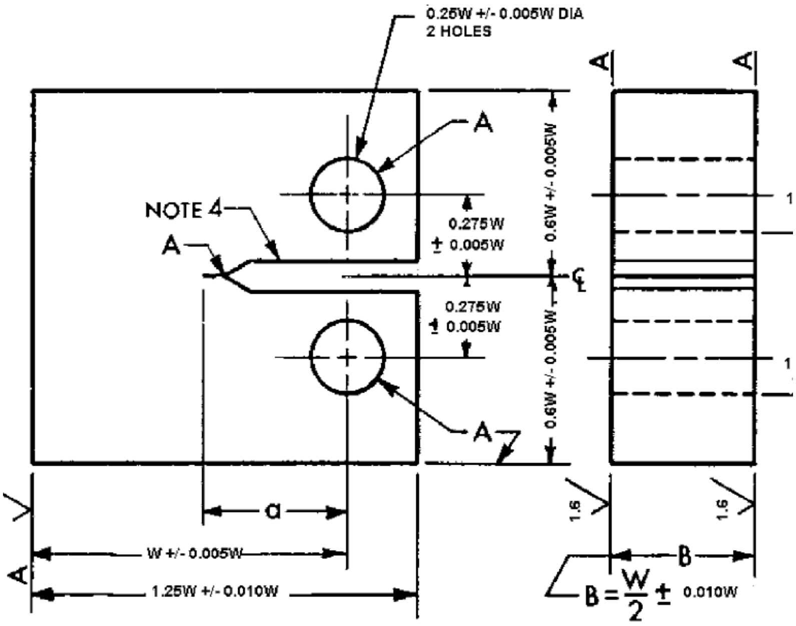


Fig 1.(a) ST at 50X (b) 30% CR at 50X

Metallographic microstructural examination of solution treatment and 30% CR sample. Cold worked samples with 30% CR have elongated grains in the direction of rolling. We use poulton reagent for etching samples.

2.5. Fracture toughness test



Sample were prepared according to ASTM E399. Sample were initially Solutionized then go for cryorolling. The initial dimension before Cryorolling are as follow:

- 30 % CR and RTR → 60mm×60mm×9.5mm
- 50% CR and RTR→ 60mm× 45mm ×12.5mm
- 70% CR and RTR →58mm × 40mm× 20.83mm
- 80 % CR and RTR→ 60mm× 30mm× 31.25mm
- ST → 62.5mm×60mm× 6.25mm

2. Kic (Plane Strain Fracture toughness) of CR sample.

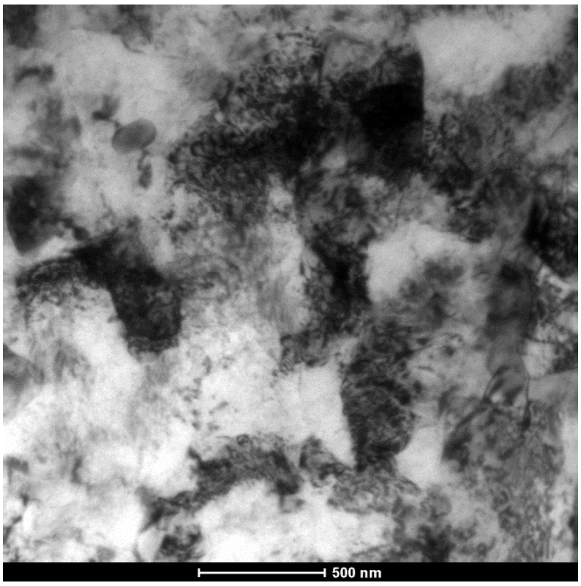
30% CR	50% CR	70% CR	80% CR	ST
26.67	32.69	62.10	65.8313	18.84

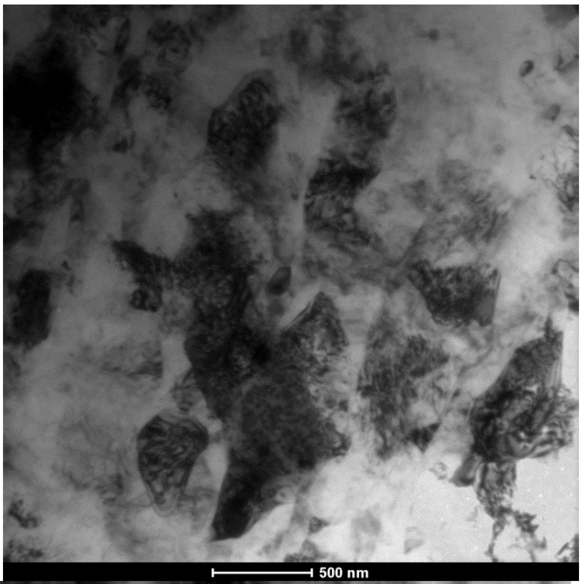
Table 3. Kic (Plane Strain Fracture toughness) of RTR sample.

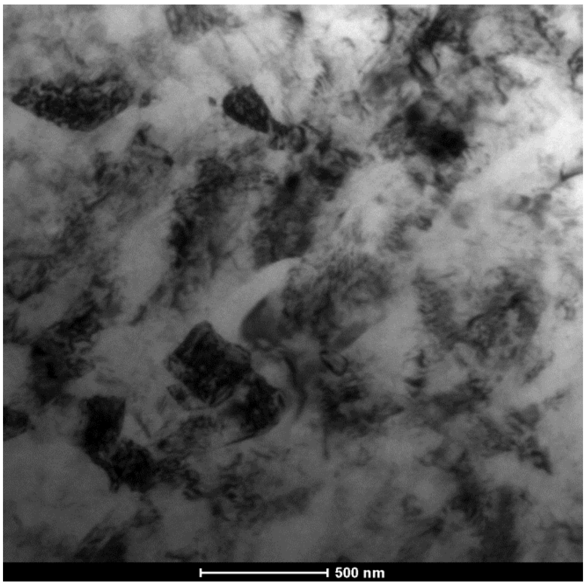
30%RTR	50% RTR	70%RTR	80%RTR
25.81	28.24	30.71	63.14

2.6 TEM (preparation of samples for TEM analysis):

In TEM investigation, the cryorolled and RTR sample were cut into 10mm×10mm square shape. These samples were thinned up to 100µm (0.1mm) thickness by using SiC emery papers of 220,400,600,800,1000,12000 and 1600 grit sizes. These samples were punched to 3mm diameter disks and the samples were cleaned with acetone for 5 miutes. The samples were Further twin-jet polishing with a solution of 20% nitric acid and the 80% methanol Liquid nitrogen is added to the solution To keep the temperature of - 30°C. After elecropolishing. The Samples were washed in ethnol for times which were kept in Jars to get better surface finish.







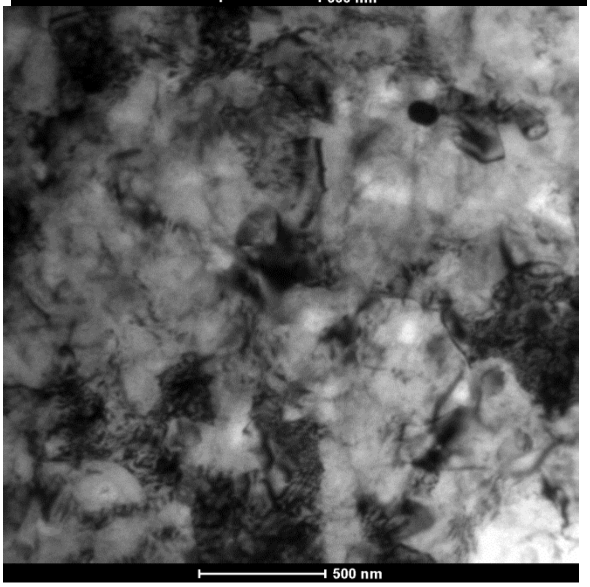


Figure 7. TEM micrographs (a) 30% CR FT (b) 50 % CR FT (c) 80% CR FT (d) 90% CR

Fig.(a) Electron micrographs (TEM) of Al 6063 alloy,30 Electron micrographs (TEM) of Al 6063 alloy, cold worked 30% of reduction in area. Presence of elon-gated (deformed) grains, dislocation tangles inside them and also small precipitates. Electron micrographs (TEM) of Al 6063 alloy cold worked 90% of reduction in area. Presence of disloca-tion tangles inside the elongated grains; there are also some cells in different regions.

3. Results and Discussion

Tensile sample were prepared according to ASTM E8 sub size. According to Hall-Petch relation

$$\partial_y = \partial_{0} + K\, d^{-1/2}$$

∂_0 indicates stress with zero dislocation, k (Hall-Petch constant) is constant and it is different for different materials. There is a grain refinement as rolling progress, d is the average grain diameter. Dislocation density increases as the further reduction given to the specimen. As the dislocation increases ,the stress required to

Move the dislocation increases and is represented by

$$\lambda = \lambda_0 + A \sqrt{\mu}$$

λ indicates stress to move dislocation in the matrix of dislocation density μ,

λ_0 indicates stress required to move dislocation in the same matrix of dislocation density zero and A is constant.

Optical micrograph of different strain is observed here. In figure (a) the solution treated have equiaxed grain with grain size 85µm. The grain is calculated on the basis of linear intercept method. In figure (b) grains are finer and are little elongated in the direction of rolling. In figure (c) Big grains are disintegrated into smaller grains with further rolling. There is enormous crystalline defects after heavily plastic deformation which leads to high hardness value.

Mechanism of an increase of fracture toughness (FT):

There is a pile up of dislocation along their slip planes which act as obstacle after plastic deformation. Microcrack nucleate at the head of the pile-up by shear stress.

Complete fracture without further dislocation movement it the pile-up is due to stored elastic energy which drives the micrograph. Microcrack is generated after fluctuation of stress from 250000 to 400000 cycles.Kic is strongly affected by the metallurgical variables such as heat treatment,texure, melting practice, impurities inclusions.

The mode of fracture is type III. It shows complete "pop in" instability where the movement of initial crack rapidly to complete failure.

TEM analysis

(a) It shows deformed grains, dislocation tangles inside them and also small precipitates.

(b) It shows presence of dislocation tangles inside the elongated grains and some dislocation wall are present in different regions.

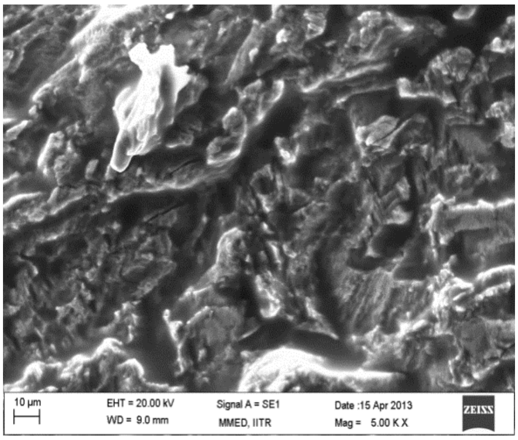
(c) It shows presence of presence of dislocation inside the elongated grains; there are some dislocation cell in different regions.

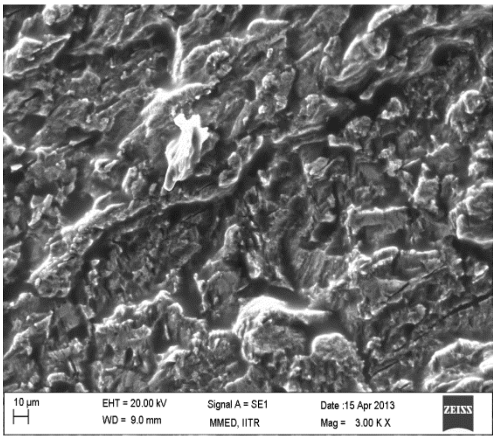
(d) It shows heavily deformed structure with dislocation tangles cells and dislocation walls.

Fractography

After seeing the fractured surface of CT- specimen, the specimen fails down in a quasi-cleavage. Dimples and tear ridges around the periphery of the facets in the in fracture toughness. The facets in the fracture surface are not true cleavage planes.

In the tensile samples, dimples rupture is characterized by cup like depressions that may be equiaxial, parabolic or elliptical depending on the stress state. This type of fracture surface shows ductile fracture.





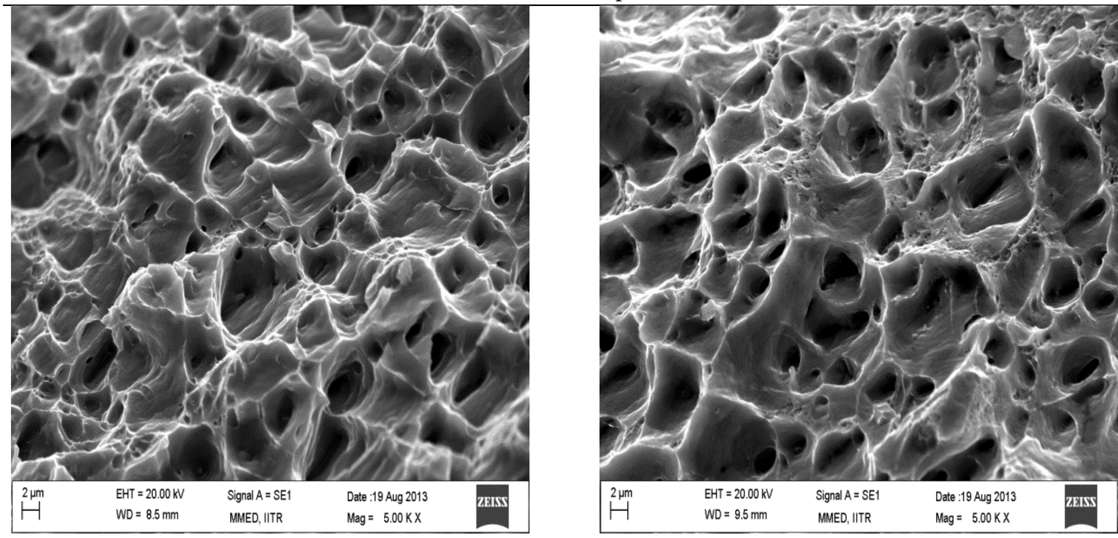


Figure 7. TEM micrographs (a) 30% CR FT (b) 50 % CR FT
(c) 80% CR FT (d) 90% CR

Conclusion

1. Materials after plastic deformation show elongated in the direction of rolling.
2. The high stored energy is retained due to suppression of dynamic recovery which leads to generation of high dislocation density (90 % CR),will result into high hardness value.
3. The tensile sample fractured in ductile manner after examined the SEM fractograph and dimples are clearly visible.
4. After examined the fracture surface, Quasi-cleavage is presence in fractograph of fracture toughness sample.
5. The optimum condition for getting high tensile strength is after overging the samples at 160^0C for 27hrs
6. Plain strain fracture toughness (Kic) increases as the reduction on samples increases.
7. The intergranular fracture is seen in CT-sample after test.

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