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Effects of Variation of Some Process Variables on Recrystallization Rate of Aluminium Alloy (6063)

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ABSTRACT

Effects of different annealing temperature, holding time and degree of deformation on recrystallization rate of Aluminium alloy (6063) were studied. Fifteen suitably dimensioned samples were prepared from Aluminium alloy (6063). Seven of these were subjected to 70% cold plastic deformation, seven to 90% and one left undeformed. All the samples were then subjected to annealing heat treatment to relief deformation-induced stresses. The average values of Yield and Ultimate tensile loads were obtained from three preliminary tensile tests as 121.33 Kgf and 192.67 Kgf respectively. From these, 70 and 90% deformations were estimated. After a metallographic test on the as-received, the samples were subjected to recrystallization annealing under different conditions of temperature (380 ^oC and 450 ^oC) and holding time (20, 30 and 40 minutes). Photomicrographs of the heat treated samples were taken from which the number of grains was counted, with the aid of a magnifying lens, from a 1cm^2 area inscribed on their surfaces. The results obtained showed that the higher the degree of cold work, the higher the rate of recrystallization, the higher the nucleation rate and the finer the grains. The higher the holding time at a given recrystallization temperature, the larger the grains due to a longer time available for grain growth. It was also deduced that recrystallization is thermally activated and its rate increases with increase in temperature.

Keywords: *recrystallization, holding time, plastic deformation, nucleation rate*

1. INTRODUCTION

Strain hardening is the phenomenon whereby a ductile metal becomes harder and stronger as it is plastically deformed. It is sometimes called work hardening or cold working because the temperature at which deformation takes place is "cold" relative to the absolute melting temperature of the metal [1]. Hot working on the other hand is a deformation carried out at temperatures higher than $0.6T_m$ (T_m is the melting temperature in Kelvin) and relatively high strain rates (10^{-1} to 10^3 s^{-1}) [5].

Strain hardening or cold working is one of the well known strengthening mechanisms for single-phase metals. It is often convenient to express the degree of plastic deformation as *percent cold work*. With an increase in percent cold work, steel, brass and copper increase in yield and tensile strength but the price for this enhancement of hardness and strength is in the ductility of the metals [1]. In industries, strain hardening is often utilized on a commercial scale to enhance the mechanical properties of materials during fabrication processes.

After a metal is plastically deformed its microstructure evidently undergoes some alterations. However, the mechanical characteristics and microstructural features of a cold worked metal may be restored to their pre-deformed condition by a suitable heat treatment during which recovery, recrystallization and grain growth occur. The amount of recrystallization is a function of time, temperature, and the degree of prior cold working [2]. The grain size depends upon the temperature of recrystallization annealing, the holding time at this temperature, the degree of previous deformation, the chemical composition of the alloy, the size of the initial grains, the presence of insoluble impurities, etc [4].

Since a number of factors come into play during these processes, many possible outcomes are obtainable. Gorelik (1981) observed that the structure of a deformed (strain hardened) material can change on recrystallization within very wide limits: from a partially recrystallized structure that retains a certain extent the original deformed structure, to a fully recrystallized structure. [2]

Gorelik (op cit) noted that the large diversity of the still unsolved problems in the theory of recrystallization is due to a number of reasons: first, fine details of the dislocation structure of deformed metal, or in essence the initial conditions of recrystallization are still unclear, as are the structures of various types of grain boundary. Without full clarity of this aspect, it is impossible to understand the mechanisms of texture formation, the role of trace impurities, etc. Second, the process of recrystallization, seemingly quite simple, is actually extremely complicated for the mere reason that it is a structure-sensitive process that comes about owing to a non-equilibrium state of the system. Third, recrystallization nuclei differ from the deformed matrix only in lattice distortion, but have the same chemical composition.

In view of the aforementioned difficulties, Gorelik (op cit) advocated that, the experimental tools for studying recrystallization be diversified and new indirect methods worked out to make appropriate conclusions.[6,7] This study therefore looks at effects of some varied parameters on the rate of recrystallization of Aluminium (6063) alloy. The varied parameters were annealing temperature, holding time and degree of deformation.

2. MATERIALS AND METHODS

2.1. Sample Preparation

The sample of aluminium alloy 6063 was machined on a turret lathe machine to produce fifteen standard tensile test pieces. All the samples were annealed at 350^{o}C to homogenize the microstructure and to eliminate induced stresses due to machining.

Three samples were subjected to preliminary tensile test (cold-deformation). The results obtained are: Test I : Yield load = 120Kgf and Ultimate tensile load = 190Kgf. Test II: Yield load = 120Kgf and Ultimate tensile load = 188 Kgf. Test III: Yield load = 124 Kgf and Ultimate tensile load = 200 Kgf.

From these results, the average Yield load and Ultimate tensile load were taken as 121.33 Kgf and 192.67 Kgf respectively.

From the foregoing, a load of 121.33 Kgf corresponds to 100% cold plastic deformation. By the same reasoning, loads of 134.87 and 173.40Kgf would produce 70 and 90% cold plastic deformation respectively. Consequently, seven samples were given 70% cold plastic deformation, seven 90% while one was left undeformed. To ensure adequate plastic deformation in the samples, they were deformed with stresses which fall between the average Yield load and the Ultimate tensile load.

2.2. Heat Treatment

All the samples were cut through their centres to expose that region of surface for metallographic test. In handling the different groups of specimen which were subjected to recrystallization annealing, a coding scheme was used. The fifteen samples were heat treated according to the following procedure and coding scheme:

(1) One sample: As-received—AR
(2) Two samples: Cold worked only—CW (70%= CW-1, 90%= CW-2)
(3) Cold worked plus recrystallization annealing—AC
    a. Two samples: Held at 380^{o}C for 20 minutes
        70%: AC1(20-1)
        90% AC1(20-2)

b. Two samples: Held at 380^{o}C for 30 minutes
70%: AC1(30-1)
90% AC1(30-2)

c. Two samples: Held at 380^{o}C for 40 minutes
70%: AC1(40-1)
90% AC1(40-2)

d. Two samples: Held at 450^{o}C for 20 minutes
70%: AC2(20-1)
90% AC2(20-2)

e. Two samples: Held at 450^{o}C for 30 minutes
70%: AC2(30-1)
90% AC2(30-2)

f. Two samples: Held at 450^{o}C for 40 minutes
70%: AC2(40-1)
90% AC2(40-2)

After the heat treatment as described above, the samples were ground on 240, 320, 400 and 600 grit emery papers. They were then polished to mirror finish and etched with [1]Keller's reagent.

2.3. Point Counting

This was done to count the number of grains per 1cm^2 area. The formula is [8,9,10]:

$$K = \frac{Z}{A} \dots\dots\dots\dots\dots\dots (1)$$

and

$$Z = M + 1/2(n) + 1 \dots\dots\dots\dots (2)$$

Where K is number of grains per unit area, Z is total number of grains in the entire 1cm^2, n is number of grains intersected by the edges and not corners of the inscribed square, A equals 1cm^2.

The area A was inscribed on each micrograph and the number of grains within the area was counted with the application of equations (1) and (2) above. The grains were made visible with the use of a magnifying glass. In effect, the number of grains per unit area represents the rate of nucleation.

3. RESULTS AND DISCUSSION

Results of counts obtained for all fifteen samples are as presented in Tables 1 and 2. The micrographs obtained at 100X are as presented in Plates 1— 4, while graphical variations of recrystallization rate (grain count) with holding time are presented in Figures 1—4.

[1] The composition is Hydrofluoric acid: 1cm3, Hydrochloric acid: 1.5 cm3, Nitric acid: 2.5 cm3 and water: 95 cm3

Table 1. Interpretation of codes and grain count.

code	Explanation	Grain count
CW-1	70% deformation, cold worked only	219
CW-2	90% deformation, cold worked only	232
AC1(20-1)	70% deformation, 380^{o}C, 20 min	179
AC1(30-1)	70% deformation, 380^{o}C, 30 min	171
AC1(40-1)	70% deformation, 380^{o}C, 40 min	167
AC1(20-2)	90% deformation, 380^{o}C, 20 min	200
AC1(30-2)	90% deformation, 380^{o}C, 30 min	184
AC1(40-2)	90% deformation, 380^{o}C, 40 min	180
AC2(20-1)	70% deformation, 450^{o}C, 20 min	143
AC2(30-1)	70% deformation, 450^{o}C, 30 min	135
AC2(40-1)	70% deformation, 450^{o}C, 40 min	131
AC2(20-2)	90% deformation, 450^{o}C, 20 min	161
AC2(30-2)	90% deformation, 450^{o}C, 30 min	153
AC2(40-2)	90% deformation, 450^{o}C, 40 min	149

Table 2. Recrystallization (grain count) as a function of % cold deformation, annealing temperature and holding time.

Code	% Deformation	annealing temperature	Holding Time	Grain Count
CW-1	70			219
CW-2	90			232
AC1(20-1)	70	380	20	179
AC1(30-1)	70	380	30	171
AC1(40-1)	70	380	40	167
AC1(20-2)	90	380	20	200
AC1(30-2)	90	380	30	184
AC1(40-2)	90	380	40	180
AC2(20-1)	70	450	20	143
AC2(30-1)	70	450	30	135
AC2(40-1)	70	450	40	131
AC2(20-2)	90	450	20	161
AC2(30-2)	90	450	30	153
AC2(40-2)	90	450	40	149

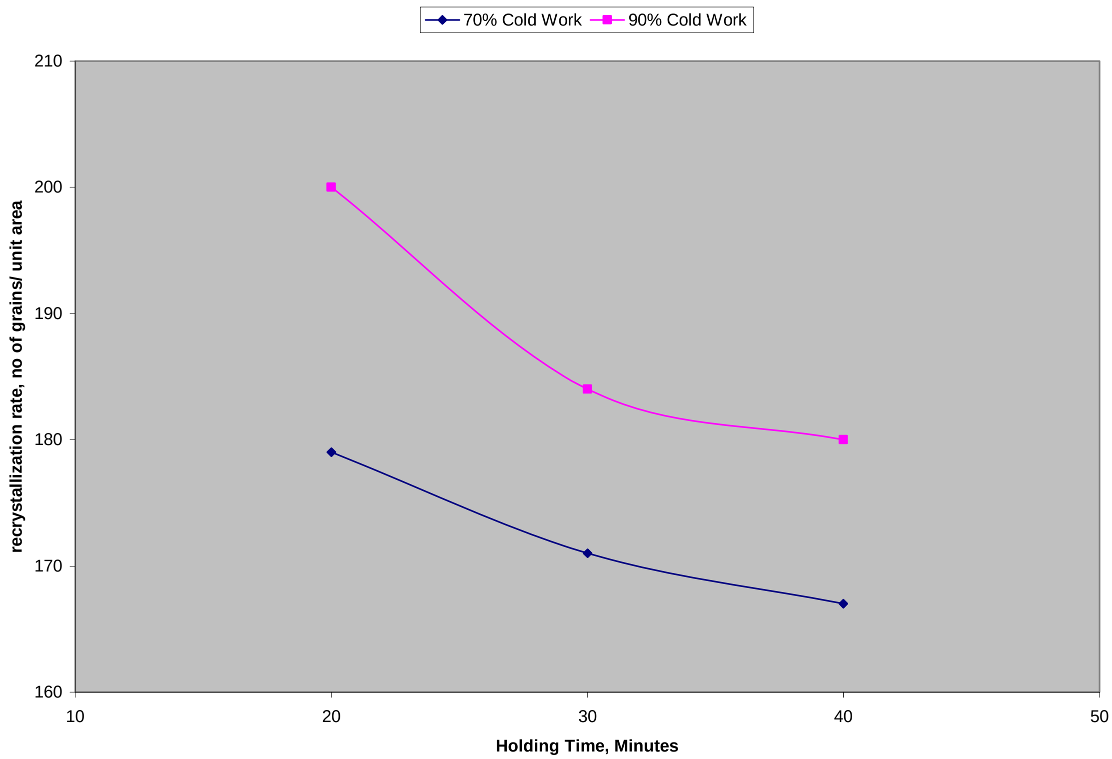

Figure 1. Effect of holding time on recrystallization rate at constant temperature (380°C).

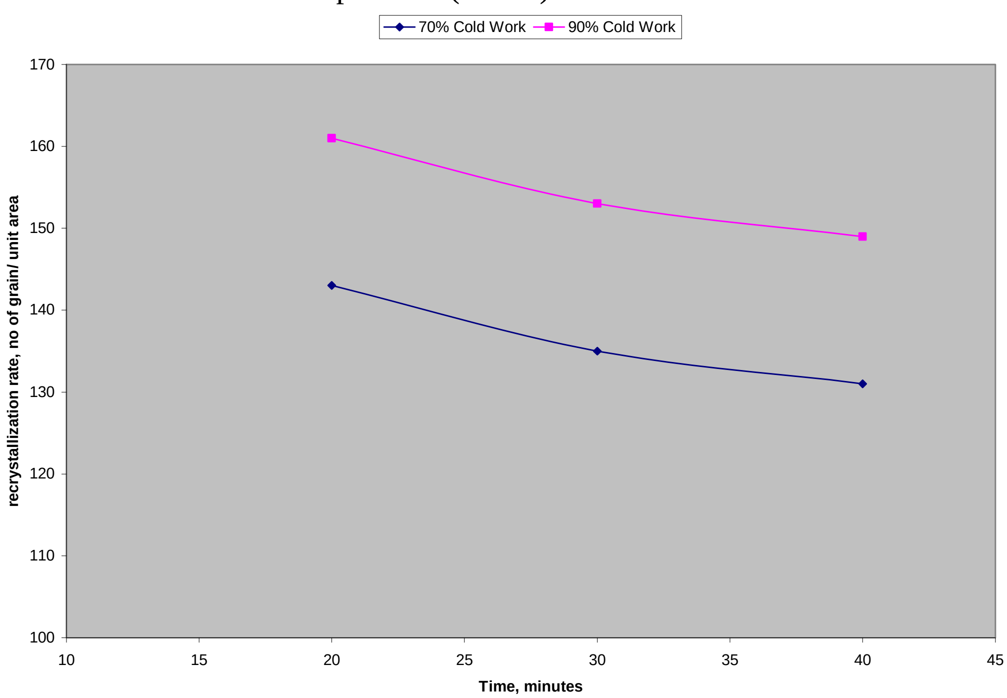

Figure 2. Effect of holding time on recrystallization rate at constant temperature (450°C).

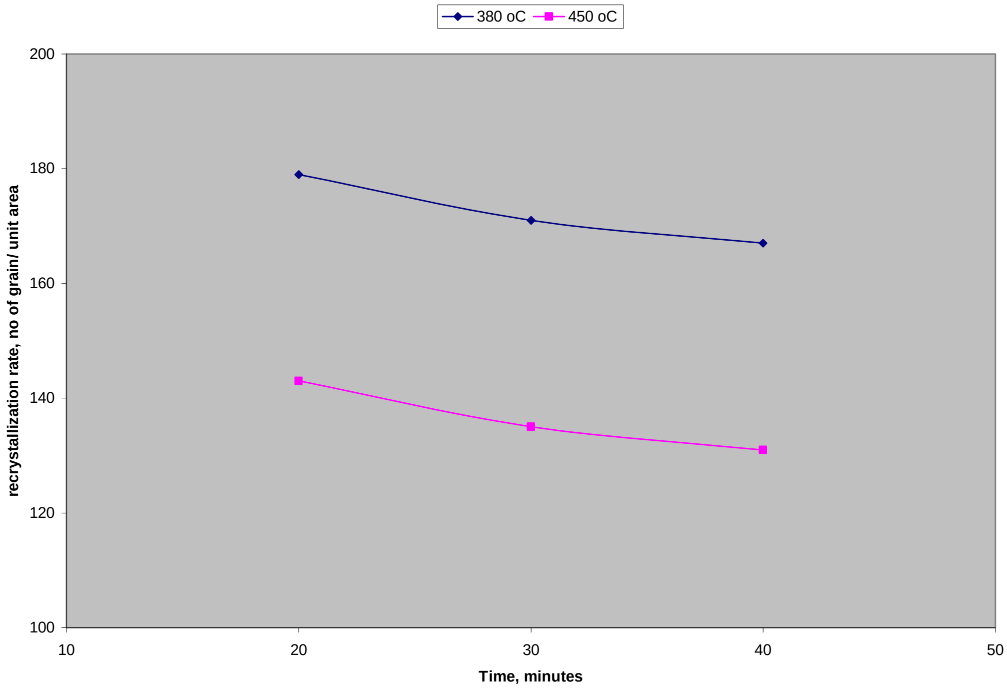

Figure 3. Effect of holding time on recrystallization rate at constant %cold deformation (70%)

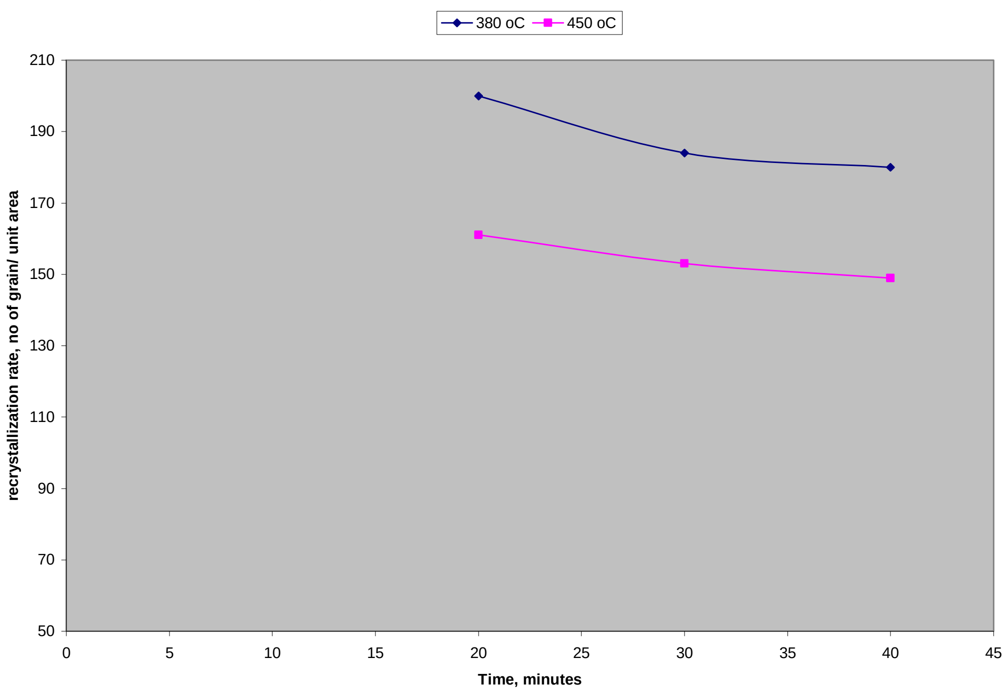

Figure 4. Effect of holding time on recrystallization rate at constant %cold deformation (90%).

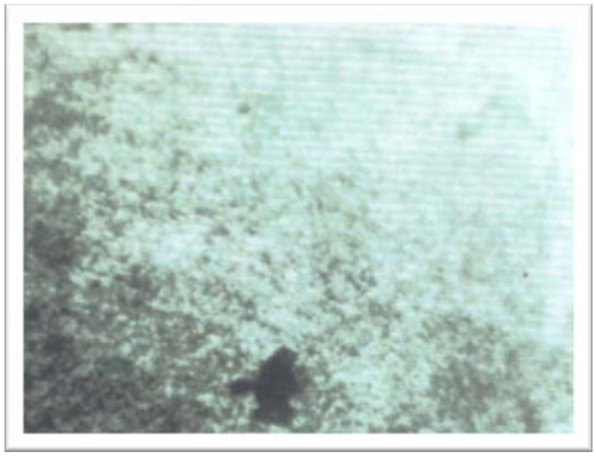

Plate1. As-received

Plate2. 70% deformation, cold worked only

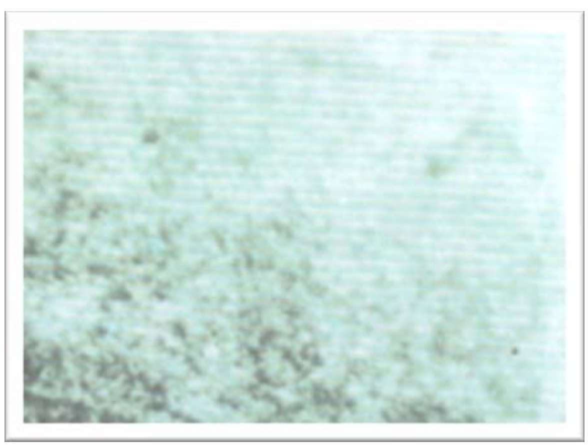

Plate3. 90% deformation, cold worked only

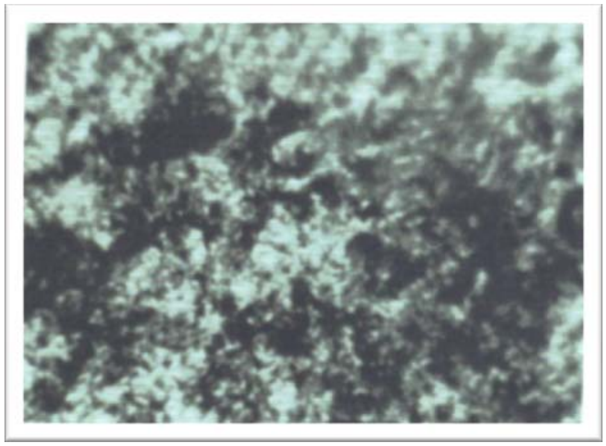

Plate 4. 70 % Deformation, 380^{o}C, 20min

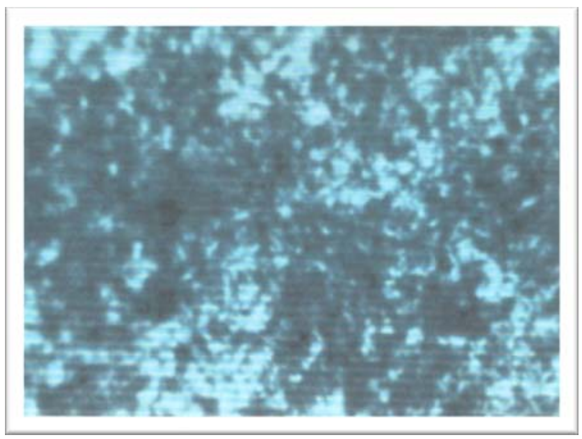

Plate 5. 70% Deformation, 380^{o}C, 30min

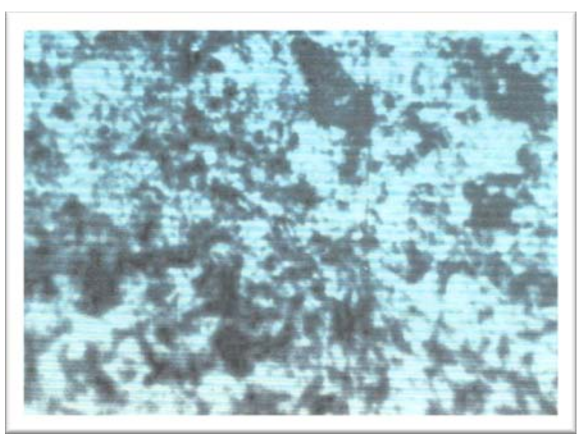

Plate 6. 70% Deformation, 380^{o}C, 40min

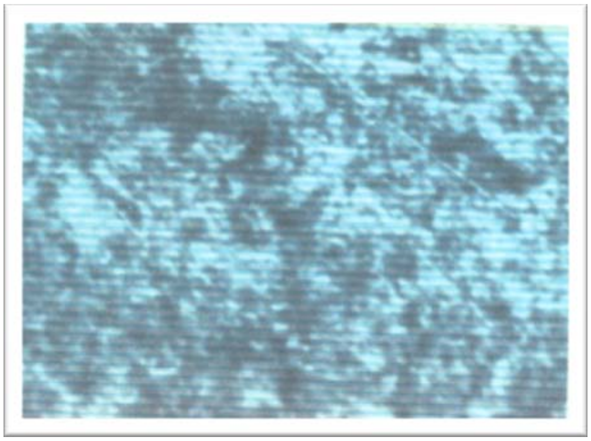

Plate 7. 90% Deformation, 380^{o}C, 20min

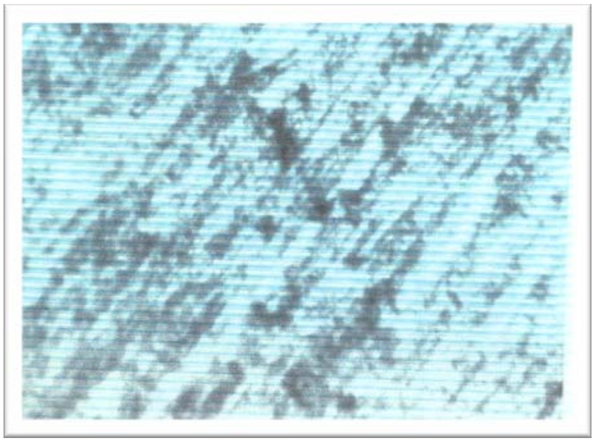

Plate8. 90% Deformation, 380^{o}C, 30min

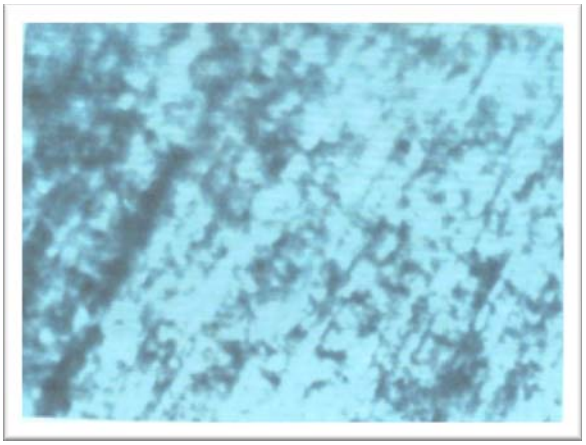

Plate9. 90% Deformation, 380^{o}C, 40min

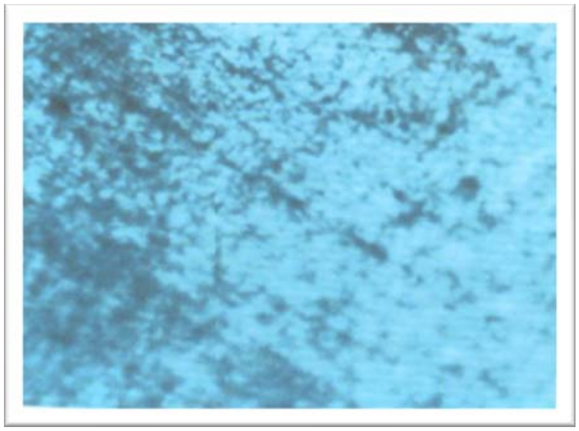

Plate10. 90% Deformation, 450^{o}C, 20min

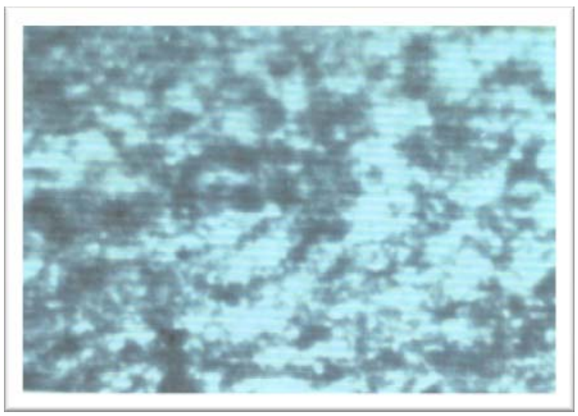

Plate11. 70% Deformation, 450^{o}C, 30min

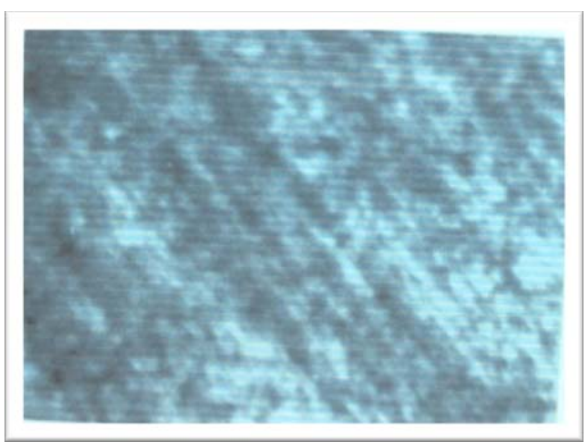

Plate12. 70% Deformation, 450^{o}C, 40min

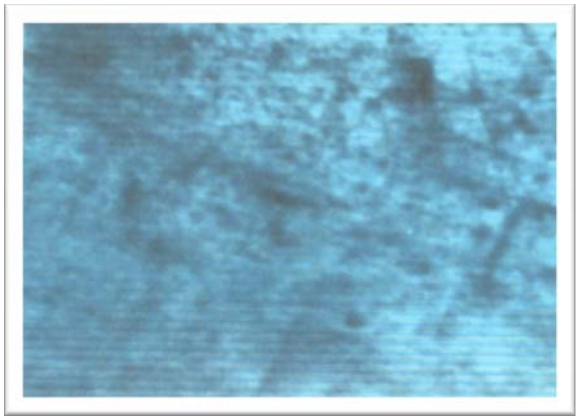

Plate13. 90% Deformation, 450^{o}C, 20min

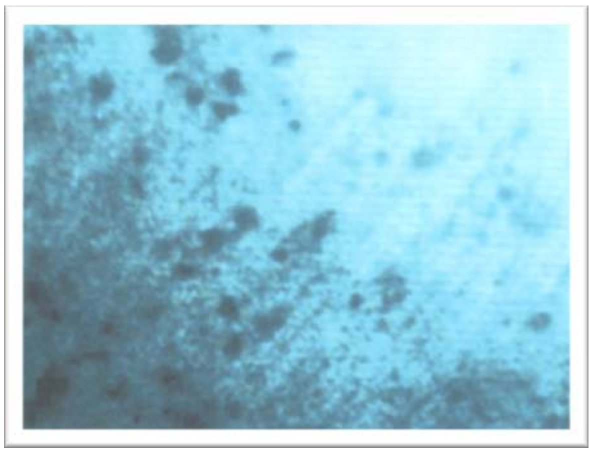

Plate14. 90% Deformation, 450^{o}C, 30min

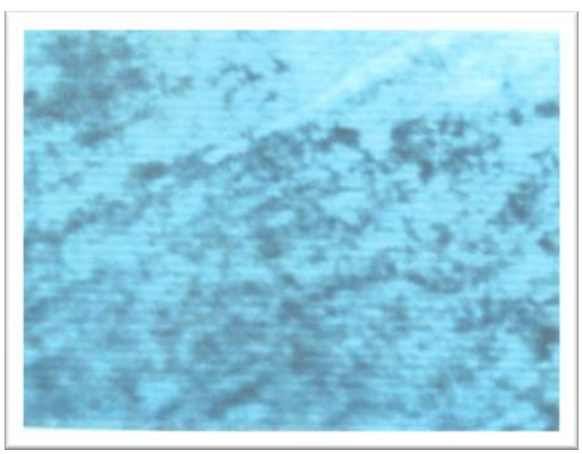

Plate15. 90% Deformation, 450^{o}C, 40min

3.1. Temperature and Recrystallization

From the analysis of the micrographs, it was found that recrystallization temperature affected the rate of crystallization. The trend observed is: the higher the temperature, the higher the recrystallization rate.

3.2. %Cold Deformation and Grain Size

The new grains formed during nucleation had undistorted lattice with equiaxed grains when compared with that of samples which were only cold worked (CW-1 and CW-2). Mechanical properties of a material are significantly affected by the size of its grains. In general, the finer the grains, the better the mechanical properties.

3.3. Effect of Holding Time

It was observed from the experiment that an increase in holding time results in a decrease in number of grains. However, the grains are larger with increased holding time. For instance, sample AC1(40-1) which was soaked at 380^{o}C in the furnace for 40 minutes was observed to have lesser grains count but bigger grains size than sample AC1(30-1) that was soaked at same temperature but for 30 minutes.

3.4. Deformation, Grain Count and Grain Size

It was observed that the higher the degree of deformation, the finer the grain size. This accounts for the observed increases in total counts per unit area for the samples having higher degree/percent of deformation. For instance, sample AC2(40-1) which was given 70% cold plastic deformation and annealed at 450^{o}C had fewer number of grains per cm^2 and larger grain size than sample AC2(40-2) that was given 90% cold deformation, annealed at same temperature and for same duration.

4. CONCLUSION

The following conclusion were drawn from the experiment

1. The higher the degree of cold work, the higher the rate of recrystallization
2. The higher the degree of cold work, the higher the nucleation rate and the finer the grains.
3. The smaller the grain size, the higher the number of grain counts.
4. The higher the holding time at a given recrystallization temperature, the larger the grains due to a longer time available for grain growth.

5. Recrystallization is thermally activated and its rate increases with increase in temperature.

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