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EFFECT OF DEFORMATION AND ANNEALING PROCESSING ON TEXTURE AND MECHANICAL PROPERTIES OF ALUMINUM ALLOY AA1200

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Abstract: *The tensile strength, hardness, percentage elongation and grain size characteristics of aluminum alloy AA1200 were studied. The alloy samples were cold rolled prior to these tests with strain between 78 – 93 %, and thereafter annealed at temperatures lying between 200 – 450 °C and at holding times of between 2- 6 hours. The results obtained showed that both the Ultimate Tensile Strength (UTS) and hardness increased with a higher degree of deformation prior to testing, but decreased as the annealing temperatures increased. The grain diameters on the other hand were seen to increase with increasing prior deformations and these fluctuate between 22.4 to 45 µm with an increase in the annealing temperatures.*

Keywords: *Cold rolled, Hardness, Ultimate tensile strength, Holding time, Annealing temperature*

1. Introduction

Currently, technological advancement has made increased demand for materials having high strength to weight ratio, high specific modulus, high electric conductivity, good corrosion resistance and good thermal conductivity. Aluminum and its alloys offer such combination of properties [1]. Aluminum and its alloys possess such better mechanical properties. When aluminum alloy AA1200 is mechanically worked, dislocation motions during cold working within metal matrix are restricted, which leads to strengthening and hardening of the metals as their shapes are changed. In addition, aluminum alloy AA1200 which has tight control over the impurities usually exhibit high electric conductivity and good thermal conductivity when cold worked [1]. Structural components made from such strengthened aluminum alloys are vital to the aerospace industry and other areas of transportation, manufacture of home utensils (for its durability) and in the building industry [2-4].

Efforts have been made over time to enhance the mechanical properties of aluminum alloys through heat treatment. Heat treatment at 520-640 °C for 14 - 12 hrs were carried out by Ibrahim [5] on aluminum alloy AA2618 using solution heat treatments and artificial aging processes. Subsequent characterization studies carried out on the solution treated samples revealed no recrystallisation at 530 °C but above this temperature recrystallisation occurred. Increasing the solution treatment temperature above 600 °C caused coarsening of the grains, resulting in significant reduction in hardness. Balogun et al [6] studied the effect of upset forging and cold rolling on the mechanical properties of Aluminum Alloy 6063 at ambient temperature. The result showed that at room temperature (32 °C), the UTS and hardness increased as the reduction in thickness of the test specimens increased from 0 to 50 percent (equivalent strain of 0.7). The gas-pore configuration in the matrix elongates and thinned down in forged sample and this occurrence promotes superior strength and hardness over cold-rolled sample [6]. The effect of cooling rate during homogenization treatment of aluminum alloy AA6063 on the low-grade cold deformation re-crystallization properties such as particle size, interparticle spacing and volume fraction of the particles were been studied by Baki and Halici [7]. Their experimental findings indicated that an increase in cooling rate caused an increase in the yield strain and a decrease in maximum grain size. Metallographic observation also revealed that increased cooling rates not only led to a decrease

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in the size of the grains but also the inter-grain spacing and volume fraction of particles [7].

The objectives of work presented here were to study the effect of the degree of deformation, annealing temperature, and holding time on the grain size and mechanical properties of strength, percentage elongation and hardness for aluminum alloy AA1200. The record of research findings available for 1xxx show that the Ultimate tensile strength is 69 MPa while for those processed by heat treatment range between 82.8 and 186.3 MPa [1]. This current study is to add to the fundamental knowledge about the behaviour of AA1xxx aluminum alloy when annealed. In order to accomplish this, aluminum alloy AA1200 specimens were deformed and annealed between 200 – 450 °C for holding time of 2 – 6 hours. This was followed by tensile testing using a Monsanto Tensometer, hardness testing using a Webster hardness, and metallographic examination.

2. Experimental Procedure

An aluminum alloy AA1200 with the nominal chemical composition given in Table 1, was obtained from Aluminum Rolling Mills of Ota town in Nigeria.

Table 1 Chemical composition of aluminum alloy AA1200 sheet

Elements	Fe	Si	Mn	Zn	Ti	Pb	Sn	Al
Weight (%)	0.400	0.200	0.050	0.050	0.025	0.030	0.030	99.215

The sheet obtained which was of thickness 7 mm, was blanked and cold rolled using a two-high reversing mill, at the Aluminum Rolling Mill Ota town, Nigeria. Test pieces of length 50 mm, width 12 mm, and thickness 1.55 mm (78 % reduction in thickness), 0.87 mm (88 % reduction in thickness), 0.67 mm (91 % reduction in thickness) and 0.43 mm (93 % reduction in thickness), in agreement with ASTM E8-6ST standard, were obtained from this parent sheet after rolling for 3, 4, 5, and 6 passes, respectively. These cold rolled test pieces were then annealed between 200 - 450 °C and for between 2 - 6 hours holding times in a muffle furnace before testing.

The hardness of the annealed test pieces were determined by using a Webster hardness tester of Model B. The stress-strain behavior of the test pieces was determined using a Monsanto Tensometer according to ASTM 1414 Standard. The grain sizes of the test pieces were measured in accordance with ASTM 112-63 grain size number determination Standard at a magnification of 100X.

3. Results and Discussion

Tables 2 to 5 show the results of the tests for hardness as well as microsctructural examination. It is evident from the tables that at the ambient temperature (prevailing room temperature) of 32 °C the UTS of the aluminum alloy increased as the degree of reduction of thickness of the material increased. Thus at 78%, 88%, 91% and 93% reduction of the material thickness the recorded values of UTS are shown in the table to be 203, 220, 238 and 247 MPa, respectively.

In Table 2, for 78 % thickness reduction, within 2 - 6 hrs hold time at 200 °C there was no appreciable change in the hardness and grain diameter except at 6 hrs hold time where the grain increased from 22.4 μm to 32 μm. But at a temperature range of 300-450 °C the hardness values decreases from 54 Hv to 24 Hv with significant increase in grain diameter (22.4 to 45 μm). However, between 300 – 350 oC annealing temperature, the hardness reduced from 50 to 34 Hv. Further increase in annealing temperature from 400 to 450 °C led to the decrease hardness to 24 Hv independent of soaking time. At annealing temperature of 300 °C, the grain diameters of the alloy samples were virtually the same for 2 – 5 hrs soaking time. But at 6 hrs the grain diameter increased to 32 μm. Increase in annealing temperature between 350 and 450 °C gave similar pattern in grain diameter increment. However, increase in grain diameter commenced at 5 hrs for 350 °C, 4 hrs for 400 °C and 4 hrs for 450° C with highest grain diameter of 45 μm at 6 hrs.

Table 3 shows the hardness and grain diameter results at 88 percent reduction deformation. Increase in the annealing temperature caused decrease in hardness. The hardness responses of the alloy at annealing temperature between 200°

C and 350 °C do not follow a regular pattern. This behaviour however is not drastically pronounced. Between the temperatures of 400-450 °C, the hardness pattern is similar to that at 78 % thickness reduction. The grain diameter distribution shows that the annealing time has significant influence on the grain size as at 450° C and between 3-4 hrs soaking time the grain diameter increased from 22.4 to 32 μm and at 5 to 6 hrs the grain diameter increased from 32 to 45 μm.

In Table 4 the hardness and grain diameter of the aluminum alloy measured after 91 % thickness reduction and annealing are shown. The hardness remains constant (24 μm) at annealing temperatures of 400 to 450 °C independent of the alloy soaking time while the grain diameter is independent of the 50 °C increase in temperature from 400 oC but increases (22.4-45 μm) with soaking time (2-6 hrs). The grain diameter of the alloy does not rany with soaking time (22.4 μm) as the annealing temperature increases from 200 °C to 300 °C, except at 6 hrs (32 μm).

Table 5 shows the results of samples deformed with 93 % reduction. The hardness of the alloy decreases with socking time at annealing temperature. The hardness is not better in any way to the as-deformed sample (54 Hv). An improvement in the grain size becomes noticeable after been soaked for 5-6 hrs at the annealing temperature. Thus, a maximum grain size of 45 μm is achieved between 350 oC – 450 oC at 6 hrs soaking time. The hardness was observed to be the same (46 Hv) at annealing temperatures of 200 °C and 300 °C within annealing time of 3 to 6 hrs and 4 to 6 hrs respectively. Similarly at annealing temperature from 400 to 450° C, the hardness remains constant at 22.4 Hv. It was generally observed in this work that grain diameters are small (22.4 – 45 μm) which characterized them as fine (Schaffer et al, 1999 and Rajput, 2006). This fine texture of the alloy may be attributed to the low level of metallic and non metallic inclusion in AA1200 alloy used.

The UTS responses of the aluminum alloy AA1200 with annealing temperatures at varied holding times in relation to the degree of deformation is shown in Figures 1 - 4. The alloy sample annealed at 200 °C, shows no significant increase in UTS when compared to that at ambient temperature [78 % (203 MPa) and 88 % (220 MPa)]. This may be linked to the absence of grain growth. Plastic deformation of Aluminum alloy AA1200 between 32 °C and below the recrystallisation temperature of 200 °C (0.3 – 0.5Tm, T_m= melting temperature) causes little or no distortion of grains and grain boundary. Subgrain boundaries begin to form with no significant change in strength and hardness as this is thin and not strong enough to hinder dislocation motion. Between 78 to 93 percent reductions in thickness, significant changes were observed in UTS for annealing temperatures between 200-450 °C and holding time of 2 – 6 hrs. The UTSs were observed to be decreasing with increasing in annealing temperature and holding time. The UTS appeared to be dependent of both annealing temperatures and holding times. This behaviour can be attributed to recovery of the alloy. The stress-relieving of the lockup stress in the matrix occurred in this time range.

The results of this study have also shown that increase of the annealing temperature will cause drastic reduction in the tensile strength of the alloy. At 78 % reduction of thickness and an annealing time of 4 hours recorded values of UTS were 203 MPa (200 °C), 196 MPa (300 °C), 153 MPa (350 °C), 98 MPa (400 °C) and 96 MPa (450 °C). This behavior was similarly observed for specimens with reductions in thickness lying between 88-93%. This decline in the values of UTS may be related to recrystallization and grain growth at temperatures above 200 °C. The values of UTS of the alloy were also seen in the figures to be dependent on the durations of soaking during annealing. The longer the holding times the lower is the values of UTS. Thus, the recrystallization of AA1200 is found to depend on the degree of prior deformation, annealing temperature and holding time [8]. With 78 – 93 % reduction of thickness, appreciable decreases in UTS values of the alloy were observed as the holding times increased from 2 to 6 hrs as more distortion occurred. For example, at 2 – 6 hrs holding time and 88 percent reduction, the UTSs decreased from 220 to 218 MPa (200 °C), 212 to 208 MPa (300 °C), 187 to 160 MPa (350 °C), 125 to 96 MPa (400 °C) and 96 to 91 MPa (450 °C) for holding times 0f 2-6 hrs. Thus the combination of holding times and percent thickness reduction (78 to 93 %) significantly enhanced the grain growth.

The as-cast coarse structure of the alloy experienced distortion at 78 – 93 % thickness reduction resulting in increased strength. (Figures 1 to 4 and Plates 1a to e). In the range of annealing temperatures and hold times considered, increase in UTS with increase in degree of deformation of the alloy was observed for temperatures up to 400°C and 450° C for 93 percent reduction. At 350 °C and holding time of 3 hours for instance, the UTS of the alloy test specimens changed from 164, 177, 183, and 194 MPa for 78, 88, 91, and 93 %, reduction in thickness. Increasing the degree of deformation causes an increase in the density of dislocations as agents of dislocations generation and multiplication of dislocations are speedily formed. During severe deformation hard intermetallic crystals are precipitated which constitute strong barriers to dislocation motion.

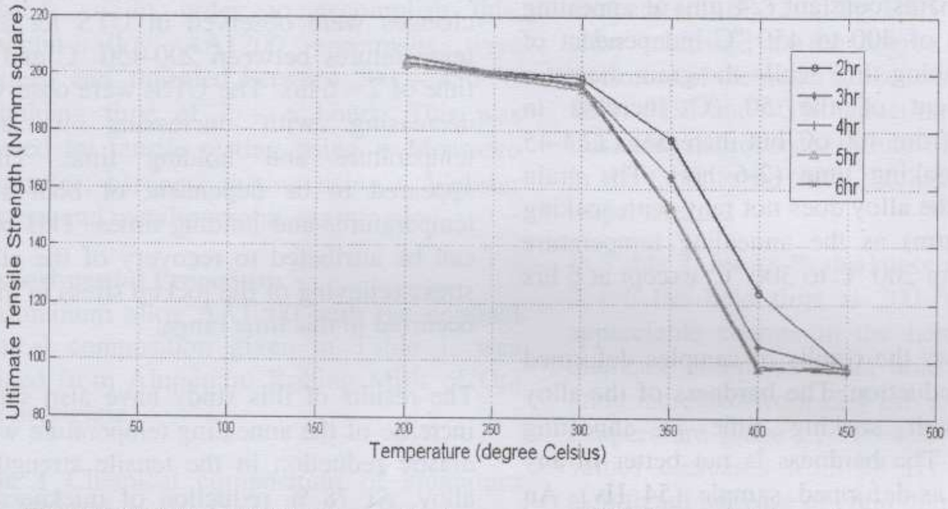

Figure 1: Variation of UTS with annealing temperature at 78% degrees of deformation

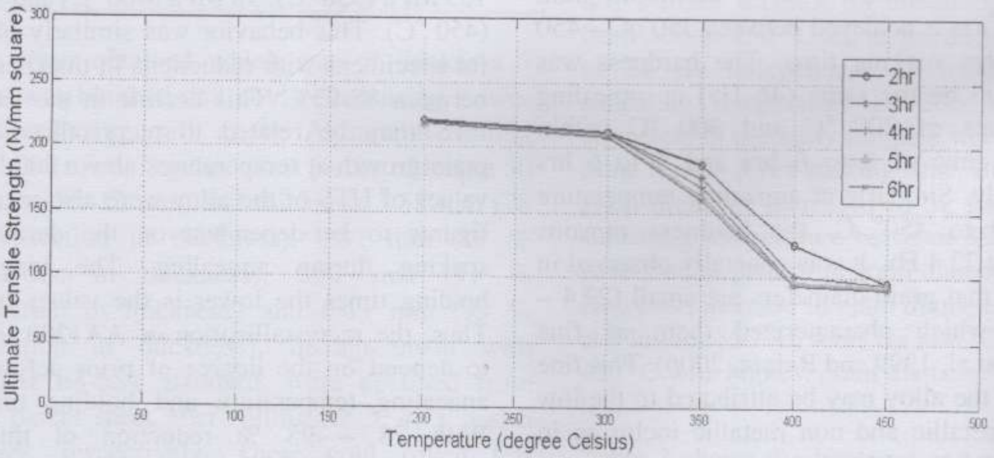

Figure 2: Variation of UTS with annealing temperature at 88% degrees of deformation

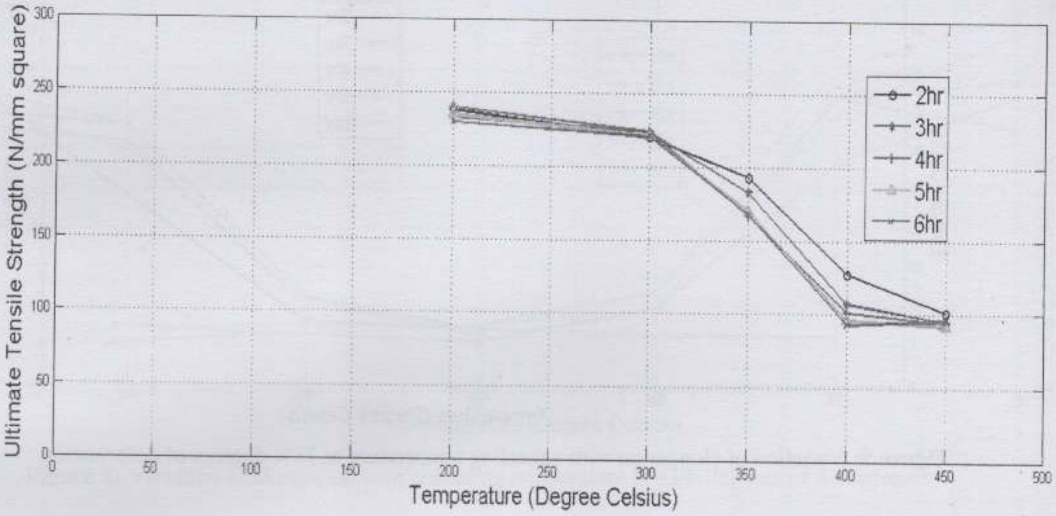

Figure 3: Variation of UTS with annealing temperature at 91% degrees of deformation

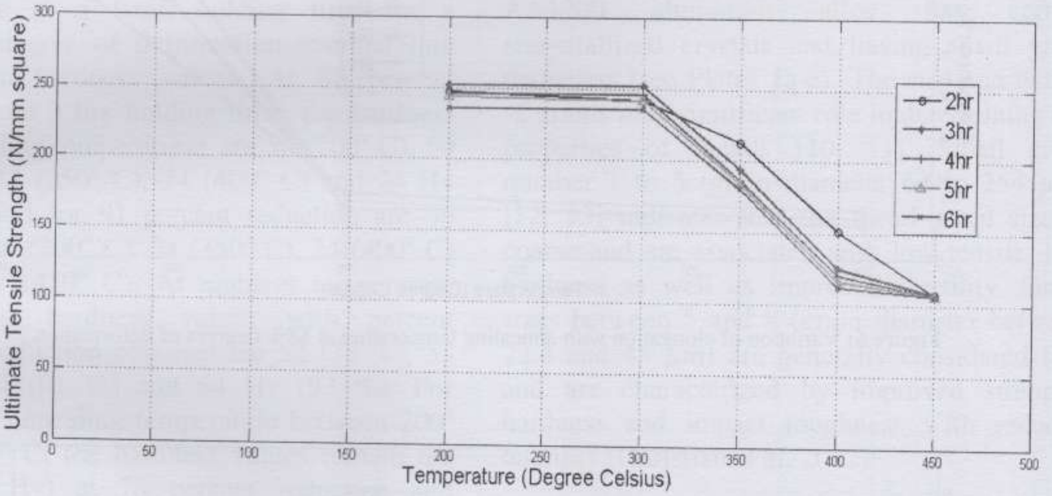

Figure 4: Variation of UTS with annealing temperature at 93% degrees of deformation

The ductility of this alloy increases (see Figures 5-8) with increase in annealing temperature. However, for some specimens at 88 % (6 hrs), 91 %(4 and 6 hrs) and 93 % (4 hrs) thickness reductions, the ductility increments occurred up to 400 °C beyond which it decline. This may be due to recrystallisation process which is characterized by slow growing crystals [9]. The percentage elongations in Figures 5-8 are higher for both initial reduction in thickness and annealing temperature. For a specimen with 78 % reduction of thickness at an annealing temperature of 400° C, the percentage elongation increases from 24 to 33% for holding times between 2 to 6 hours (see Figure 5). Similar trends are presented in Figures 6 - 8. For the same annealing temperatures and hold times, increase in the degree of initial deformation (percentage reduction in thickness) cause a decrease in percentage elongation (Figures 5 – 8). For instance at 350 °C and a holding time of 5 hours, percentage elongations of 10, 7, 6 and 6 %, were obtained of 78, 88, 91 and 93 % initial thickness reductions.

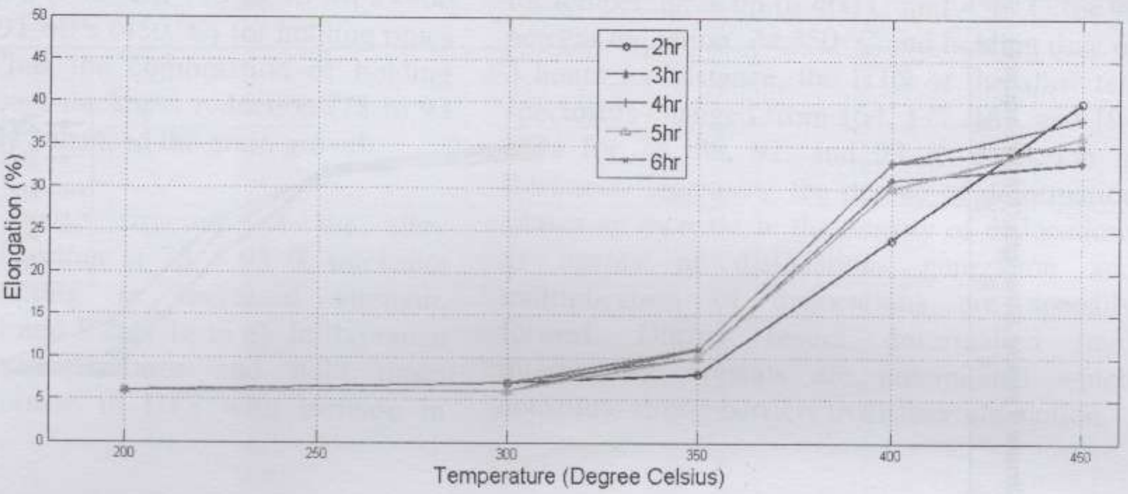

Figure 5: Variation of elongation with annealing temperature at 78% degrees of deformation

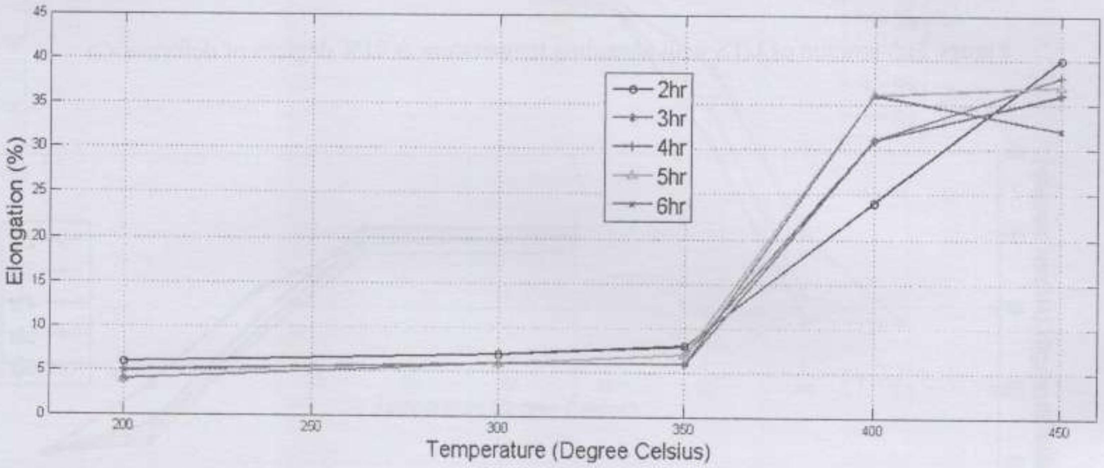

Figure 6: Variation of elongation with annealing temperature at 88% degrees of deformation

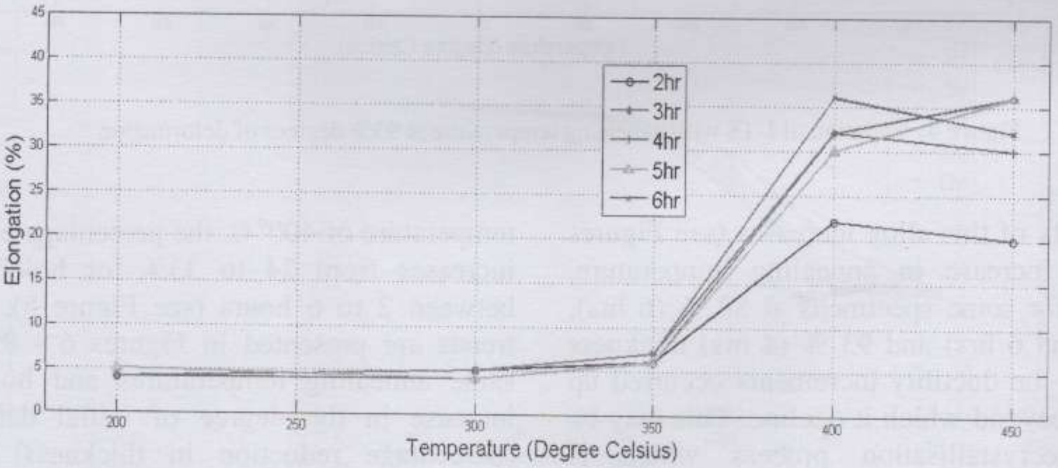

Figure 7: Variation of elongation with annealing temperature at 91% degrees of deformation

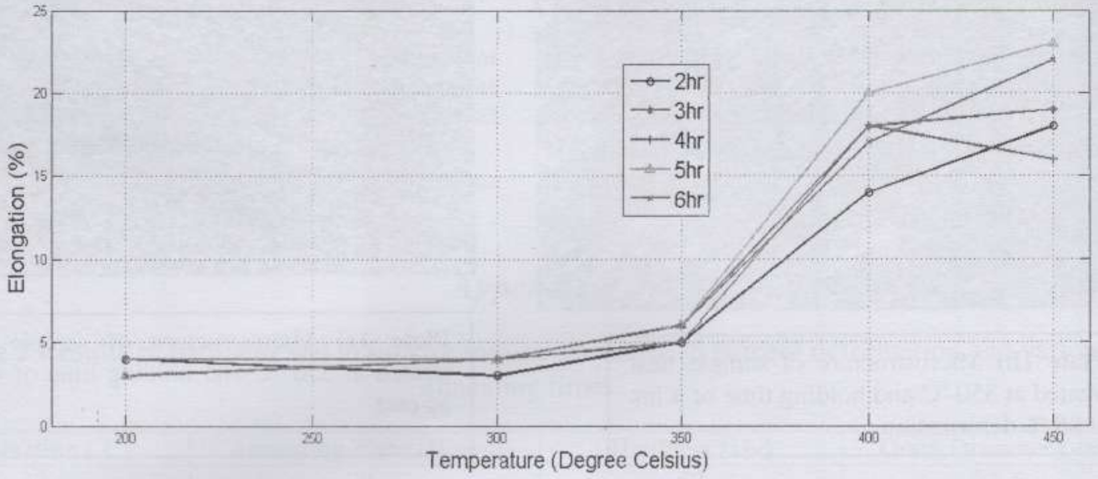

Figure 8: Variation of elongation with annealing temperature at 93% degrees of deformation

Table 2 - 5 show significant changes in the hardness of samples with increase in degree of deformation. An increase in annealing temperature at a fixed holding time for a particular degree of deformation resulted into decrease in hardness values. At 88 percent reduction and 3 hrs holding time, the hardness with annealing temperatures are 50 (200° C), 50 (300° C), 42 (350° C), 24 (400° C) and 24 Hv (450° C) and for 91 percent reduction are 46 (200° C), 46 (300° C), 34 (350° C), 24 (400° C) and 24 Hv (450° C). At ambient temperature (32°C), the hardness values with percent thickness reduction obtained are 52 (78 %), 53 (88 %), 54 (91 %) and 54 Hv (93 %). For increase in annealing temperature between 200° C and 300° C, the hardness values remain the same (50 Hv) at 78 percent reduction and holding times of 2-6 hrs. Similarly, hardness of 24 Hv is obtained at annealing temperatures of 400° and 450° C and 42 Hv and 34 Hv at 2 and 3-6 hrs (350° C) holding time respectively. Further strain from 78 to 88 % does not have significant effect on the hardness at 200° C as holding times increase from 2 to 6 hrs. The hardness remains constant at 400° C and 450° C at the process holding times. However, at 300° and 350° C annealing temperatures with the same holding times its values lies between 34 and 50 Hv. At strains of 91 and 93 percents, increase in annealing temperatures caused decrease in hardness at 2-6 hrs holding times while the hardness of the alloy remained constant at 400° C and 450° C.

During annealing, "as-cast" (see Plate 1e) AA1200 aluminum alloy has certain recrystallized crystals and having small grain diameters (see Plates 1a-e). The size and nature of grains play significant role in determining the properties of metals [10, 11]. Small grain number 1 to 5 (grain diameter 64 to 254 μm) [12, 13] indicates that the metal grain size is coarse and are associated with low tensile, low hardness as well as improved ductility. Grain sizes between 5 and 8 (grain diameter between 22.4 and 45 μm) are generally considered fine and are characterized by improved strength, hardness and impact toughness with reduced ductility (Christian et al, 2002).

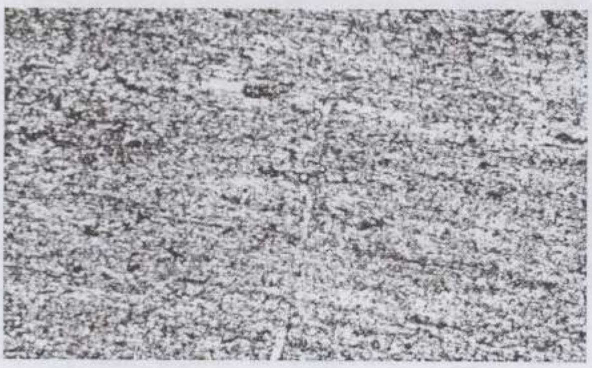

Plate 1a) Microstructure of sample heat treated at 350 °C and holding time of 4 hrs at 78 % deformation

Plate 1b) Microstructure of sample heat treated at 350 °C and holding time of 4 hrs at 88 % deformation

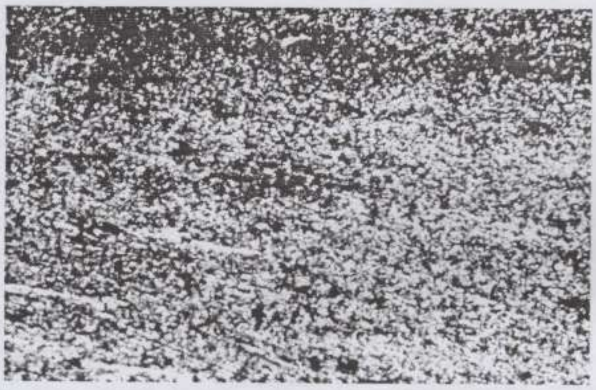

Plate 1c) Microstructure of sample heat treated at 350 °C and holding time of 4 hrs at 91 % deformation

Plate 1d) Microstructure of sample heat treated at 350 °C and holding time of 4 hrs at 93 % deformation

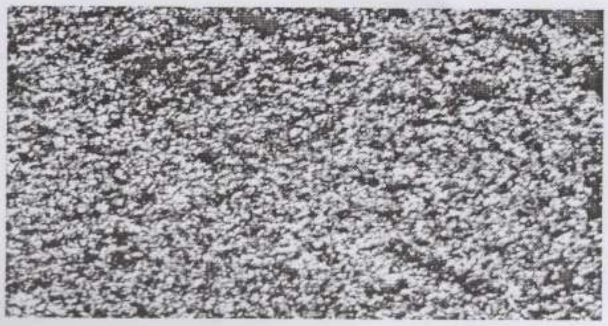

Plate 1e) Microstructure of sample heat treated at 350 °C and holding time of 4 hrs as-cast

4. Conclusions

The following conclusions can be drawn from this study:

- When the degree of deformation by cold rolling is constant, the time required for recrystallization of AA1200 aluminum alloy place decreases with increasing annealing temperature. At 78 percent reduction for examples, the UTS decreases from 205 MPa to 124 MPa at corresponding annealing temperature of 200 °C (6 hrs) and 400 °C (2 hrs).
- The higher the degree of prior deformation of AA1200 alloy, the lower the temperature required for recrystallization.
- Increase in degree of deformation of AA1200 alloy would produce fine grain diameters of range between 22.4 and 45 μm.

References

1) Myer, k. (2000). *Handbook of materials selection.* John Wiley & Sons. New York.

2) Suraj, R. (2001). Metal-matrix composites for space application. *JOM*, 53(4), 14-17.

3) Zainul, H. (2009). Precipitation strengthening and age-hardening in 2017 aluminum alloy for aerospace application. *European Journal of Scientific Research*, 26(4), 558-564.

4) Perovic, A.; Perovic, D..D.; Weatherly, G.C.; and Lioyd, D.J. (1999). Precipitation in aluminum alloys AA6111 and AA6016. *Scipta Materialia*, 41(7), 703-708.

5) Ibrahim, O. (2007). A study on the re-solution heat treatment of AA2618 aluminum alloy. *Materials Charaterisation,* 58(3), 312-317.

6) Balogun, S. A.; Esezobor, D.E.; and Adeosun, S.O. (2007). Effect of deformation processing on the mechanical properties of aluminum alloy 6063.

Metallurgical and Materials Transaction, 38(7), 1570-1574.

7) Baki, K. M.; and Halici, I. (2007). The effect of homogenization and recrystallisation heat treatments on low-grade cold deformation properties of AA6063 aluminum alloy. *Materials Letters*, 61(4-5), 944-948.

8) Polmear, I.J. (1995). *Light Alloys: Metallurgy of the Light Metals*. London, Arnold.

9) Higgins, R.A. (1974). *Engineering Metallurgical. Edward Arnold Publishers,* Part 1, London.

10) Schaffer, P.J.; Ashok, S.; Stephen, D. A.; and Steven, B.W. (1999). *The science and design of engineering materials.* McGraw-Hill, Second Edition.

11) Rajput R.K. (2006). *Engineering materials and metallurgy.* Chand and Company Ltd, New Delhi.

Appendix

Table 2 Results of hardness and grain size measurements at 78 percent deformation and various annealing times.

Temperature (°C)	Annealing Time (Hours)	Hardness (Hv)	Grain Diameter (μm)
32	0	52	22.4
200	2	50	22.4
	3	50	22.4
	4	50	22.4
	5	50	22.4
	6	50	32
300	2	50	22.4
	3	50	22.4
	4	50	22.4
	5	50	22.4
	6	50	32
350	2	42	22.4
	3	34	22.4
	4	34	22.4
	5	34	32
	6	34	32
400	2	24	22.4
	3	24	22.4
	4	24	32
	5	24	32
	6	24	32
450	2	24	22.4
	3	24	22.4
	4	24	32
	5	24	32
	6	24	45

Table 3 Results of hardness and grain size measurements at 88 percent deformation and various annealing times.

Temperature (°C)	Annealing Time (Hours)	Hardness (Hv)	Grain Diameter (μm)
32	0	53	22.4
200	2	50	22.4
	3	50	22.4
	4	50	22.4
	5	46	22.4
	6	50	32

300	2	50	22.4
	3	50	22.4
	4	46	22.4
	5	50	22.4
	6	46	32
350	2	34	22.4
	3	42	22.4
	4	42	22.4
	5	34	32
	6	34	32
400	2	24	22.4
	3	24	22.4
	4	24	32
	5	24	32
	6	24	32
450	2	24	22.4
	3	24	22.4
	4	24	32
	5	24	32
	6	24	45

Table 4 Results of hardness and grain size measurements at 91 percent deformation and various annealing times.

Temperature (°C)	Annealing Time (Hours)	Hardness (Hv)	Grain Diameter (μm)
32	0	54	22.4
200	2	54	22.4
	3	53	22.4
	4	50	22.4
	5	50	22.4
	6	50	32
300	2	42	22.4
	3	46	22.4
	4	46	22.4
	5	42	22.4
	6	34	32
350	2	42	22.4
	3	34	22.4
	4	32	22.4
	5	32	32
	6	32	32
400	2	24	22.4
	3	24	22.4
	4	24	32
	5	24	32
	6	24	45
450	2	24	22.4
	3	24	22.4
	4	24	32
	5	24	32
	6	24	45

Table 5 Results of hardness and grain size measurements at 93 percent deformation and various annealing times.

Temperature (°C)	Annealing Time (Hours)	Hardness (Hv)	Grain Diameter (μm)
32	0	54	22.4
200	2	50	22.4
	3	46	22.4
	4	46	22.4
	5	46	32
	6	46	32
300	2	50	22.4
	3	50	22.4
	4	46	32
	5	46	32
	6	46	32
350	2	34	22.4
	3	34	22.4
	4	34	32
	5	34	32
	6	32	45
400	2	24	22.4
	3	24	32
	4	24	32
	5	24	45
	6	24	45
450	2	24	22.4
	3	24	32
	4	24	32
	5	24	45
	6	24	45