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Development and Strengthening of 2219 Aluminium Alloy by Mechanical Working and Heat Treatment

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Abstract: The wrought aluminum alloy 2219 was developed using an induction furnace followed by forging and hot rolling for the improvement of properties. Then the alloy was solution treated at 535°C for 48 min followed by water quenched and then aged at 210, 230 and 240°C for different time period. The maximum tensile strength of 411 MPa and hardness of 113.7 HV were achieved at 210°C after 4 h aging. The tensile strength of 368.12 MPa and hardness of 95.32 HV were obtained at 240°C after only 1.5 h aging time. The strength and hardness values of aged alloy specimens obtained in this work were reasonably higher (strength 51% and hardness 81%) than the specimens which were solution treated and quenched. Microstructures of the aged specimens also provided an evidence of dispersion of second phase precipitates particles in the single phase matrix.

Key words: 2219 Aluminum alloy, age hardening, tensile strength, hardness, microstructure

INTRODUCTION

Aluminium and its alloys have been in use since long in industrial applications, due to their many useful properties such as low density, good electrical and thermal conductivity and corrosion resistance in many environments (Dwight, 1999). Pure Aluminium with a tensile strength ranging from about 90 to 140 MPa depending upon the temper type but for structural use it has to be strengthened by alloying; the strongest alloys have a tensile strength of over 500 Mpa (Dwight, 1999; Shanmugasundaram *et al*., 2006). The optimum strengthening of Al is achieved by alloying and heat treatments (Taminger and Hafley, 2002). High strength aluminium alloys have been used in aircraft and spacecraft construction for many years, particularly Al-Cu from the 2000 series (According to the Designation of the American Association USA). Alloy 2219 is an Al-Cu binary alloy commonly used as an aerospace material due to its characteristics such as excellent weldability as well as weld strength. These properties extend its use to other applications (Starke and Staley, 1996; Smith, 1981).

In 2219 Al alloy, strain hardening of solution treated products accelerates the response to artificial aging and produces higher tensile strengths. This type of work of artificial aging response is used for certain Al-Cu-Mg alloys (Dudas and Thompson, 1970) but had not been used commercially for Al-Cu alloys before the development of 2219 alloy (Hatch, 1984). According to Taminger and Hafley (2002) heat treated deposits of Al-2219 to the T6 temper, the microstructures of the deposits exhibited features more typical of cast material rather than these associated with wrought products (Kovacs *et al*., 1977). Many researchers have studied evaluation of microstructure, tensile strength and fracture toughness of precipitation hardened of 2219 Al alloy (Kovacs *et al*., 1977; Garrett and Knott, 1978; Melander and Persson, 1978; Srivatsan, 1992; Mukhopadhyay *et al*., 1994; Li *et al*., 1999; Ringer and Hono, 2000; Waterloo *et al*., 2001; Dumont *et al*., 2003). Rosen *et al*. (1982a) measured sound velocity, attenuation and hardness to study the precipitation hardening in 2219 alloy. Measurements as a function of aging time at various temperatures were found to exhibit prominent changes related to the formation of precipitates. Rosen *et al*. (1982b) also studied the influence of precipitation kinetics during ageing on electrical conductivity and hardness of 2024 alloy.

During the present research work the 2219 Al alloy was locally developed by using the locally available raw

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materials. The alloy was tested for mechanical properties. The results were verified by microstructural studies. The objective of this research work was to study the effect of aging time and temperature on mechanical properties of 2219 Al-alloy. The main emphasis was to find the minimum aging time at any investigated temperature to achieve the maximum UTS and hardness values.

MATERIALS AND METHODS

Materials: 2219 Al-alloy was prepared using locally available high purity constituents as shown in Table 1.

Methods: Al-ingot, Al-Si, Al-Mn, Al-Cu were heated together in an induction furnace at 750°C. An addition of cleansing fluxes was made at same temperature. Heating was continued and maintaining a layer of covering fluxes protected metal. When all of these metals were in molten state, Al-Mg and Zn were added and finally $AlTiB_5$ was incorporated. The furnace heating was then stopped and fluxing layer was removed thoroughly. The degassing procedure was then adopted with the help of plunger by using nitrogen degassing tablets. A vigorous reaction took place and on completion of reaction plunger was taken out of the crucible and slag was removed. The molten metal was then poured at 720°C using pre-heated metallic mould.

Forging operation was performed with the open die and hammer forger of capacity 400 kg. Similarly, hot rolling was carried out upon the samples by using STANAT rolling mill.

The alloy was solution treated at 535°C in muffle type furnace for 48 min and then followed by the aging at 210, 230 and 240°C for different period of time.

Mechanical testing: Using SHIMADZU Autograph AG50K NISD-MS-Series carried out the tensile tests. The test samples were prepared according to the ASTM (E8M-00) standards. The Ultimate Tensile Strength (UTS) of each specimen was calculated from the graph by dividing the maximum load value by the original cross sectional area of the specimen. The hardness of each specimen was measured according to ASTM standard (E92) by using SHIMADZU Micro Hardness Tester HMV-2 Series.

Microstructure analysis: Optical micrographs were taken using Nikon Optiphot UFX-DX microscope. All specimens were cold mounted and hand ground on a wet emery paper of grade 240, 320, 400 and 600 grit, respectively. Polishing was carried out using cloth impregnated with 6, 3 and 1 μm diamond paste lubricated with paraffin.

Table 1: Composition of metals and master alloys used for the development of 2219 alloy

Element	Cu	Si	Mg	Mn	Fe	Zn	Ti	Al
Wt. %	5.95	0.08	0.04	0.317	0.19	0.03	0.05	Balance

RESULTS AND DISCUSSION

Chemical analysis: Using the optical emission spectroscopy (Emission GNR ITALY metal lab 75-80 J) checked the composition of the prepared alloy. The achieved composition of the alloy is shown in Table 2. The result showed that the composition of fabricated alloy is according to the standard.

Microhardness and tensile strength: The test samples were characterized for hardness and tensile strength at 210, 230 and 240°C, the obtained results are mentioned in Table 3.

Results of tensile testing of the alloy aged at different temperatures in the range of 210 to 240°C are graphically represented in Fig. 1.

The ultimate tensile strength versus time at aging temperature of 210°C shows that the maximum ultimate tensile strength of 410.9 MPa is achieved after aging for 4 h, after which the strength reduces to 352 MPa. Test samples aged at 230°C showed the maximum ultimate tensile strength of 370.7 MPa after 3.5 h aging and at 240°C the maximum ultimate tensile strength of

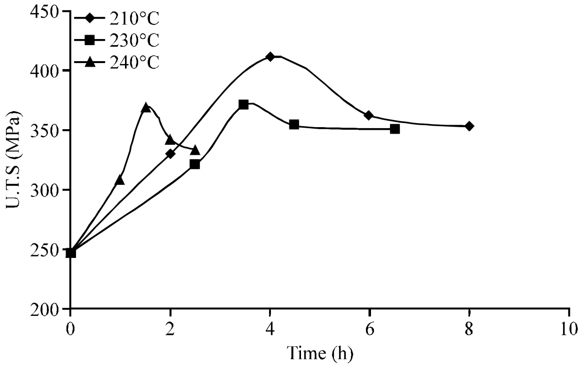

Fig. 1: Graphical representation of UTS versus time at temperature 210, 230 and 240°C

Table 2: Achieved composition of the 2219 Al-alloy

Raw material	Form	Percentage
Al	Ingot	99.9
Al-Cu	Master alloy	50:50
Al-Si	Master alloy	50:50
Al-Mg	Master alloy	75:25
Al-Mn	Master alloy	40:60
$AlTiB_5$	Master alloy	85:10:5
Zn	Ingot	99.9

Table 3: Hardness and tensile strength of 2219 Al alloy at different level of temperature

Time (h)	Hardness (HV)	Tensile strength (Mpa)
210°C		
0	63.37	245.63
2	77.23	329.36
4	113.76	410.90
6	98.74	361.59
8	90.81	352.07
230°C		
0.0	63.37	245.63
2.5	73.58	320.90
3.5	88.03	370.70
4.5	85.48	353.60
6.5	83.72	349.80
240°C		
0.0	63.37	245.63
1.0	91.19	308.37
1.5	95.32	368.12
2.0	90.27	341.17
2.5	88.58	332.88

368.12 MPa is obtained after much less aging time of 1.5 h. From these results it may be seen that the ultimate tensile strength initially increases with aging time reaching a maximum value and then decreases as expected in such aging heat treatment. The strength increased initially because the formation of precipitates. After achieving maximum strength it gradually fall, its all because of over aging (Raghavan, 1998). It is also observed hat with the increase in aging temperature respond the maximum strength in less time. However, the maximum value of ultimate tensile strength obtained at 210°C is higher than those observed at 230 and 240°C which may be explained on the basis of the possibility of not using an aging time which could provide a value higher than these. Increase in strength observed from these graph may be related to the beginning of precipitation process leading to the formation of GP (Guinier Preston) zones (Smith, 1993) which hinder the movement of dislocation within alloy. The decrease in ultimate tensile strength values after reaching a maximum is termed as over aging and is mostly related with the formation of coherent second phase particles which increases in size with time and reduce the hinderness to the dislocation moment to a certain extent.

Similar behavior was observed for hardness versus time graph at temperatures 210, 230 and 240°C. The Fig. 2 represents the maximum hardness values versus temperature. The maximum hardness values obtain 113.76 HV at temperature 210°C for aging time of 4 h.

In a previous work on the same alloy (Jabeen and Ahmad, 2007) the aging was carried out at 190, 210 and 230°C and maximum ultimate tensile strength of 370 Mpa was obtained at aging temperature 210°C after 6 h where as in the present work the maximum ultimate tensile strength of 410.9 MPa was obtained at same temperature after 4 aging. Also the ultimate tensile strength values of 370.7 and 368.12 MPa were obtained at 230 and 240°C, respectively after much less aging time.

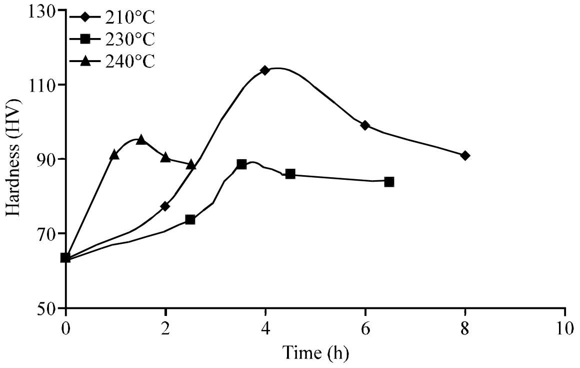

Fig. 2: Graphical representation of vickers hardness versus time at temperature 210, 230 and 240°C

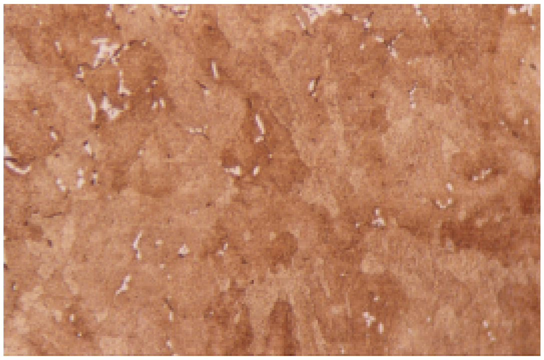

Fig. 3: Precipitate formation in microstructure of the specimen aged at 210°C for 4 h: 200X

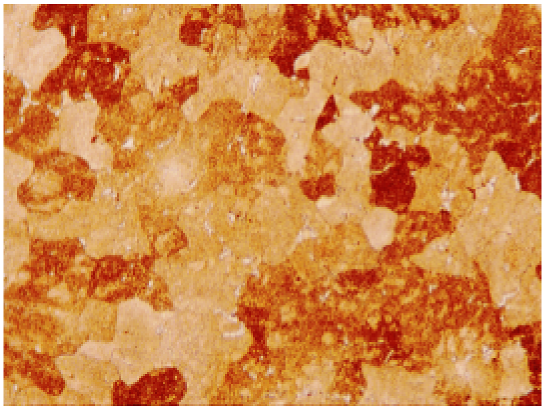

Fig. 4: Precipitate formation in microstructure of the specimen aged at 240°C for 1.5 h: 200X

Figure 3 and 4 showed micro structure of representative samples which were aged at 210°C for 4 h and 240°C for 1.5 h, respectively. From these microstructures few intermetallic precipitates may be seen distributed in the matrix however, the finer precipitates such as (CuFe) Al_6, Cu_2FeAl_{17}, (CuFeMn) Al_6 and $Cu_2Mn_3Al_{20}$, $CuAl_2$ etc are expected to form which are not clearly seen in optical micrograph (Mondolfo, 1976; Van Horn, 1967).

CONCLUSION

Following conclusions may be drawn from the above work:

- The maximum ultimate tensile strength (410.9 MPa) and hardness (113.76 HV) were achieved at 210°C in 2219 Al-alloy after aging for 4 h
- It was noted that maximum strength and hardness generally decreased at higher temperatures with increasing aging time
- The maximum ultimate tensile strength (368.12 MPa) and hardness (95.32 HV) were obtained in a much less time at the highest temperature of 240°C
- Some coarse particles of the second phase which are expected to precipitate out during aging were also seen in the photomicrographs of the alloy aged at 210 and 240°C

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REFERENCES

Dudas, J.H. and D.B. Thompson, 1970. Improved Sintering Procedures for Aluminum P/M Parts. Aluminum Company of America, USA.

Dumont, D., A. Deschamps and Y. Brechet, 2003. On the relationship between microstructure, strength and toughness in AA7050 aluminum alloy. Mater. Sci. Eng. A, 356: 326-336.

Dwight, J., 1999. Aluminum Design and Construction. Taylor and Francis Group, New York.

Garrett, G.G. and J.F.Knott, 1978. The influence of compositional and microstructural variations on the mechanism of static fracture in aluminum alloys. Metal. Mater. Trans. A, 9: 1187-1201.

Hatch, J.E., 1984. Aluminum: Properties and Physical Metallurgy. American Society of Materials, Metals Park, Ohio.

Jabeen, I. and R. Ahmad, 2007. A study of aging effects on hardness and tensile properties 2219 aluminum alloy. Proceedings of the International Conference of Materials Science and Technology and Exhibition (MS and T Partner Societies), Sept. 16-20, American Society for Materials, USA., pp: 1429-1438.

Kovacs, I., J. Lendvai, T. Ungar, T. Turmezey and G. Groma, 1977. The properties of an AlZnMg alloy deformation strengthened by Guinier-Preston zones. Acta Metall., 25: 673-680.

Li, X.Z., V. Hansen, J. Gjonnes and L.R. Wallenberg, 1999. HREM study and structure modeling of the ç phase, the hardening precipitates in commercial Al-Zn-Mg alloys. Acta Mater., 47: 2651-2659.

Melander, A. and P.A. Persson, 1978. The strength of a precipitation hardened AlZnMg alloy. Acta Metall., 26: 267-278.

Mondolfo, L.F., 1976. Aluminum Alloys: Structure and Properties. Butterworths, Boston, London.

Mukhopadhyay, A.K., Q.B. Yang, S.R. Singh, 1994. The influence of zirconium on the early stages of aging of a ternary Al-Zn-Mg alloy. Acta Metall. Mater., 42: 3083-3091.

Raghavan, V., 1998. A First Course Materials Science and Engineering. Prentice Hall of India (Pvt.) Ltd., India, pp: 212-123.

Ringer, S.P. and K. Hono, 2000. Microstructural evolution and age hardening in aluminium alloys: Atom probe field-ion microscopy and transmission electron Mater. Charact., 44: 101-131.

Rosen, M., E. Horowitz, S. Fick, R.C. Reno and R. Mehrbian, 1982a. An investigation of the precipitation-hardening process in aluminum alloy 2219 by means of sound wave velocity and ultrasonic attenuation. Mater. Sci. Eng., 53: 163-177.

Rosen, M., E. Hotowitz, L. Swartzendruber, S. Fick and R. Mehrabian, 1982b. The aging process in aluminum alloy 2024 studied by means of eddy currents. Mater. Sci. Eng., 53: 191-198.

Shanmugasundaram, T., B.S. Murty and V. Subramanya, 2006. Development of ultrafine grained high strength Al-Cu alloy by cryorolling. Scripta Materialia, 54: 2013-2017.

Smith, W.F., 1981. Structure and Properties of Engineering Alloys. McGraw-Hill, New York.

Smith, W.F., 1993. Structure and Properties of Engineering Alloys. 2nd Edn., McGraw-Hill Inc., New York, USA.

Srivatsan, T.S., 1992. Microstructure, tensile properties and fracture behaviour of aluminium alloy 7150. J. Mater. Sci., 27: 4772-4781.

Starke, Jr. E.A. and J.T. Staley, 1996. Application of modern aluminum alloys to aircraft. Prog. Aerospace Sci., 32: 131-172.

Taminger, K.M.B. and R.A. Hafley, 2002. Characterization of 2219 aluminum produced by electron beam freeform fabrication. Proceedings of 13th Solid Freeform Fabrication Symposium, Aug. 5-7, Austin, TX., pp: 482-489.

Van Horn, K.R., 1967. Aluminum: Properties, Physical Metallurgy and Phase Diagrams. American Society for Metals, Metals Park, Ohio, pp: 49-54.

Waterloo, G., V. Hansen, J. Gjonnes and S.R. Skjervold, 2001. Effect of predeformation and preaging at room temperature in Al-Zn-Mg-(Cu,Zr) alloys. Mater. Sci. Eng. A, 303: 226-233.