Refinement and redistribution of intermetallic compounds in AA 7xxx alloyby rolling and their effect on formability studies

K. SAI PRASAD[1], R. MOHANA RAO[2], V. GANESH[3], A. PARAMESH[4], V.V.RAVI KUMAR[5]

[1]Associate Professor, Department of Mechanical Engineering, Nadimpalli Satyanarayana Raju Institute of Technology, Visakhapatnam, Andhra Pradesh, India
[2,3,4,5] Student, Mechanical Engineering, Nadimpalli Satyanarayana Raju Institute of Technology, Visakhapatnam, Andhra Pradesh, India

---***---

Abstract- Thermo-mechanical treatment, in particular, cold-rolling is a unique technique to produce super high strength aluminum alloys with ultrafine grained structure. In the present study, 7xxx series aluminum alloy with high alloying additions (Zn: 12%, Mg: 3% Cu: 2%, and 0.5% SC wt.) was rolled at different temperatures (Room temperature). Since the alloy consists of segregated compounds along the boundaries, non-isothermal step rolling was carried out to condition the alloy and followed by rolling. Optical microscopy, SEM, hardness and tensile testing were conducted on the rolled alloy for understanding the phase changes and evaluating the mechanical properties. It is noticed that the ductility of the rolled alloy is getting re-stored with desirable strength by short annealing. The formability of the rolled sheets of all conditions was investigated.

Keywords: Aluminium alloys, Rolling, Ultra-fine Structure, Formability.

1. Introduction

A material possessing desirable properties is the recent requirement in engineering applications. Light weight, formability and strength are the most important properties opted by the designer in the selection of a material for most of the advanced engineering applications. In specific, AA7xxx series alloys are widely used in aerospace applications due to their good specific strength, formability, resistance to various corrosive media, etc. [1-3], either soluble or insoluble in nature. It was proved that cryo rolling of aluminum alloys had resulted in ultrafine grains (UFG) with sufficient ductility. The cold rolling process cannot be used to produce UFG structure in AA7xxx alloys due to its high strength, poor ductility and high stacking fault energy. When the forming operation was carried out at room temperature, the quality of the surface of a final product was poor. It had been reported that the surface quality and improved ductility in high strength alloy could be obtained by conducting forming operation in the temperature range from 100 to 450˚C [4-5]. Cryo-rolling has been established as one of the leading routes to produce nano-crystalline (NC) / UFG pure metals Cu, Al, Ni from its bulk counterparts by deforming them at cryogenic temperature. Wang et al. (2002) produced UFG structure of commercial pure Cu by cryo-rolling at the lower temperature compared to SPD method at ambient temperature [6]. The tensile strength was decreased while the elongation was improved gradually with increasing annealing temperature [7]. Low-temperature aging treatment on cryo-rolled Al 7075 and Al 2024 alloy was carried out by Zhao et al.(2005) and Cheng et al.(2007), who obtained huge improvement of [8-9]. Formability of the material is the capability of the material to undergo plastic deformation to a given shape, without defects. Forming limit diagrams (FLD) were used for the prediction of deformation factors that could result in the failure of the material under different strain ratio. FLDs proposed as an important tool in the forming behavior of sheet metals and in the optimization of manufacturing industries as reported by Kleiner et al. (2008) [10]. Kirstensson et al. (2006) reported a numerical study of micro- mechanical modeling affecting the formability [11]. To evaluate the ductile fracture of Al alloy sheets was proposed by Daoming Li, et al. (2004) and predict the forming limit of Al alloys, proved an effective tool [12].

2. Experimental Procedure

Al–12Zn–3Mg–2.5Cu-0.5%SC (wt. %) alloy billet was prepared by controlled process parameters. A sample coupon for rolling at appropriate temperature was cut from the billet. The sample size of 35mm × 35mm × 6mm was used for non-isothermal rolling and followed by cold rolling. The alloys were multi-pass rolled from 6 mm to reduction in thickness 1mm. Cold rolled alloy were subjected to short annealing at 200°C for 10 min. The sample size of 30mm×30mm×1mm was used for conduct of formability studies. Chemical etching method printed by the grid patterns. The circle diameter of the grid was 2.5 mm. Forming up to fracture was carried out on a double action hydraulic press of capacity 2000 kN using standard die and punch set up. Figure 1 depicts the photograph of the formability testing machine and sample used for test. The major diameter, minor diameter values, the major strains (ε_1) and the minor strains (ε_2) were calculated using the following empirical equations.

Major strain (ε_1) = ((major diameter – 2.5 mm) / 2.5mm) x 100 -------- 1

Minor strain (ε_2) = ((minor diameter – 2.5 mm) / 2.5mm) x 100 -------- 2

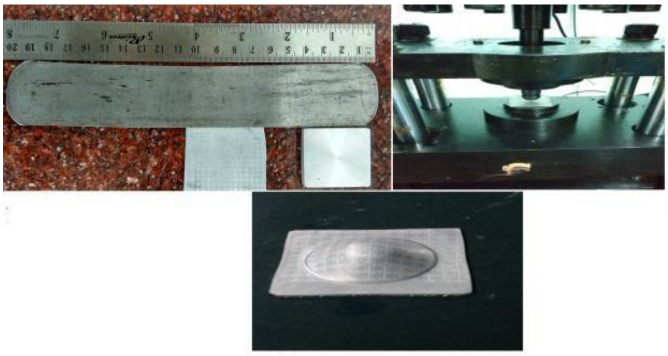

Fig.1 Photograph of rolled AA7xxx + 0.5% SC alloy in different processing conditions and flow diagram of rolled and sheet metal forming

3. Results and Discussion

3.1 Micro structural Characterization

Micrographs of AA7xxx alloy AA7xxx with 0.5%SC aluminium alloy various conditions shown in fig. 2 (a & b). The microstructure of AA7xxx with Scandium shows α-Al matrix and complex intermetallic compounds. The grain size of cast alloy is the range of 20-30μm. After addition of the 0.5wt (%) scandium grain size range of 5-10μm. Microstructures of solutionized and aged AA7xxx+0.5%SC alloy are shown in fig. 2 (c & d). The structure of aged alloy shows dispersoids and fine precipitates. During solutionizing treatment, the chemical composition of matrix grains is getting changed. The grains of solutionized alloy are rich with Cu and Zn than that of grains of cast alloy. The complex intermetallic compounds are predominantly Al_6CuMg_4, Al_2Cu and $MgZn_2$ and Al_2CuMg by non-equilibrium solidification addition of 1wt (%), Scandium form dispersoids Al_3Sc.

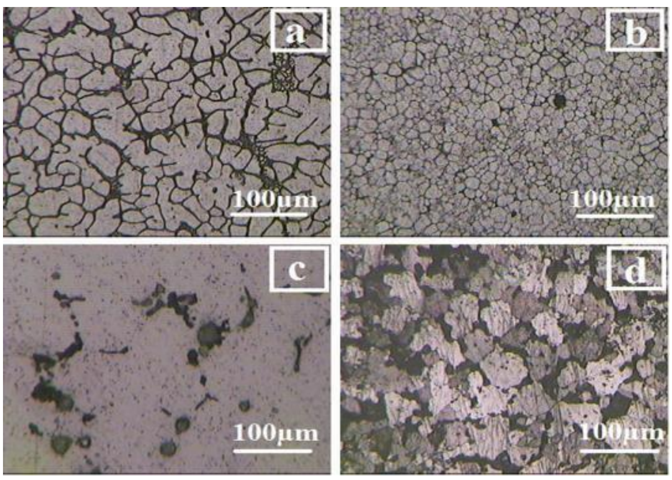

Fig. 2 Microstructure of AA7xxx alloy with different processing conditions (a) AA 7xxx Cast, (b) AA 7xxx + 0.5%Sc (b) AA 7xxx + 0.5%Sc Solutionized and (c) AA 7xxx + 0.5%Sc Aged.

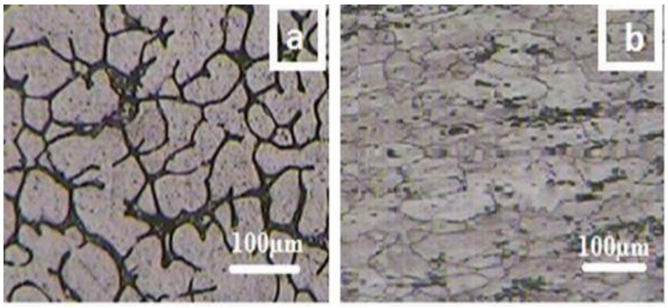

Fig. 3 Microstructure of AA 7xxx alloy a) Cast b) Room temperature rolling and

3.2 Mechanical properties

Mechanical properties of AA7xxx and AA7xxx with 0.5% Sc alloy with different conditions are shown in Table 4.1. The tensile strength of AA7xxx and AA7xxx with 1% Sc cast, solutionized aged and rolled alloy is 424MPa, 480MPa, 359MPa, 642MPa and 687MPa and the elongation is 3%, 2%, 7%, 6.5% and 7.6 %, respectively. AA7xxx and AA7xxx with 1% Sc alloys has resulted good strength by non-homogenous nature and poor ductility of cast alloys. Age hardened aluminium alloy exhibits enhanced mechanical properties than that of cast alloy and solutionized alloy with 6.4% ductility. A good combination strength and ductility in bulk nano-structured AA7xxx with 0.5% Sc alloy had been developed by introducing very fine secondary phase particles in the matrix. Enhancement of strength and ductility in alloy was attributed to an accumulation of dislocations, resistance to dislocation-slip by compounds, solid solution, precipitation hardening and dispersion hardening. Precipitation hardening has resulted increment in UTS than that of cast alloy with good incremental ductility. This is attributed by nano-scale size of precipitates distributed homogeneously throughout the matrix addition of AA7xxx + 0.5%Sc alloy. Hardness values of the cast and the rolled alloy are tabulated (Table- 1) along with the standard deviation. It is noticed that the rolling operation has enhanced the hardness of the alloy. In the case of the rolled alloy, the increment in hardness is mainly attributed to elongated grains and formation of nano size compounds. The cold-rolled alloy exhibits superior hardness value than that of as received alloy. It is due to grain refinement, the formation of nano size compounds and increased dislocation cell structure in cold-rolled condition. Rolling alloys gives better mechanical properties with increased ductility. The increasing strength in the cold rolled alloy is mainly improved by the combined effects of solid solution strengthening, dislocation, elongated grain and nano size fine compounds.

Table 1.Mechanical properties of AA7xxx alloy with different conditions

S.No	Conditions	(Hv0.3)	Yield strength (MPa)	UTS (MPa)	% Elongation
1	Cast	171±5	358±10	424± 10	3.0±1
2	Cast + Sc (0.5%)	188±5	432±10	480± 10	2.0±1
3	Solutionized + Sc (0.5%)	150±5	272±10	359± 10	7.0±2
4	Aged + Sc (0.5%)	205±5	525±10	642± 10	6.4±2
5	Room temperature rolling	218±5	630±10	687± 10	7.6±2

Figure 4 shows the photographs of formability tested sheets of AA7xxx +0.5 SC alloy sheets. As received AA7xxx alloy shows poor formability than that of cold rolling because of segregation of compounds along the grain boundaries. While comparing the formability of cold-rolling limiting dome height there is no significant variation. Cold rolling with short annealing with short annealing Limiting dome height increases significantly. The cold rolling with short annealing exhibits excellent formability without fracture upto deformability at 1.4cm in dome height.

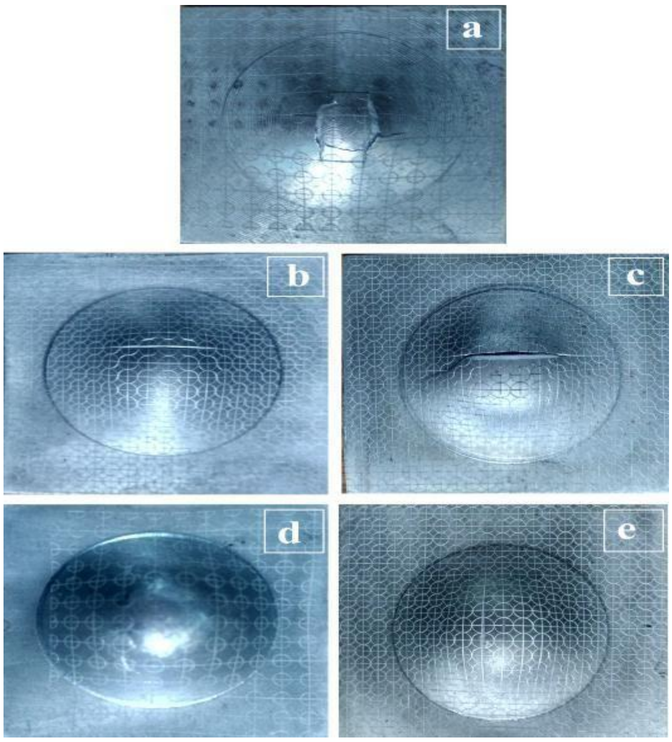

Fig. 4 Al–12Zn–3Mg–2.5Cu alloy a) Billet, b) Cold rolling, c) Cold rolling d) Cold rolling after short annealing 200°C 2mins and e) Cold rolling after short annealing 200°C 2mins.

4. Conclusions

1. Cast AA 7xxx, AA7xxx + 0.5 % SC wt. (%) alloy shows coarse intermetallic compound, both soluble and insoluble, homogeneously distributed throughout the matrix and grain boundaries.

2. Precipitation behaviour of AA 7xxx and AA7xxx + 0.5% SC wt. (%) alloy is a bit sluggish due to the presence of insoluble intermetallic compounds which delay the solutionizing of soluble compounds and evolution of fine precipitates during ageing. It is interesting to note that there is a precipitate free zone around the insoluble coarse intermetallic compounds, attributed by restricted atom diffusion around insoluble compound

3. Precipitation hardening has resulted increment in UTS than that of cast alloy with good incremental ductility. This is attributed by nano-scale size of precipitates distributed homogeneously throughout the matrix addition of AA7xxx + 0.5% SC

4. Precipitation hardening has resulted 40% increment in UTS than that of cast alloy with 6% ductility. This is attributed by nano-scale size of precipitates distributed homogeneously throughout the matrix.

5. The cold rolling alloy exhibits better formability than that of cast samples at identical reduction with 70% with short annealing. Cold rolled AA7xxx alloy sheets exhibit fair formability. The formability is higher in T-T strain region compared to T-C or PS regions.

5. References

1. M. Dixit, R.S. Mishra, K.K. Sankaran, 2018. Structure–property correlations in Al 7050 and Al 7055high-strength aluminum alloys. Materials Science and Engineering A, 478: 163–172.

2. Tolga Dursun, Costas Soutis, 2019. Recent developments in advanced aircraft aluminium alloys. Materials and Design, 56: 862–871.

3. MohammadAlipour, BaharakGhorbanian Aghdam, HamidEbrahimi Rahnoma, M. Emamya, 2013. Investigation of the effect of Al–5Ti–1B grain refiner on dry sliding wear behaviorof an Al–Zn–Mg–Cu alloy formed by strain-induced melt activation process. Materials and Design, 46: 766–775.

4. A.Abolhasani, A.Zarei-Hanzaki, H.R.Abedi, M.R.Rokni, 2012. The room temperature mechanical properties of hot rolled 7075 aluminium alloy Materials and Design, 34: pp. 631–636.

5. Yu-guo Liao, Xiao-qi Han, Miao-xia Zeng, Man Jin, 2014. Influence of Cu on microstructure and tensile properties of 7XXX series aluminum alloy. Materials and Design.

6. Wang, Y., M. Chen, F. Zhou and E. Ma (2002) High tensile ductility in a nanostructured metal, Nature, 419, 912-915.

7. Bo WANG, Xian-hua CHEN, Fu-sheng PAN, Jian-jun MAO,Yong FANG. Effects of cold rolling and heat treatment on microstructure and mechanical properties of AA 5052 aluminum alloy. Trans. Nonferrous Met. Soc. China 25 (2015) 2481–2489.

8. Zhao, Y.H., X.Z. Liao, Y.T. Zhu and R.Z. Valiev (2005). Enhanced mechanicalproperties in ultrafine grained 7075 Al alloy,*J. Mater. Res.*, 20, 288-291.

9. Cheng, S., Y.H. Zhao, Y.T. Zhu and E. Ma (2007). Optimizing the strength and ductility of fine structured 2024 Al alloy by nano-precipitation. ActaMater.,55, 5822-5832.

10. M. Kleiner, M. Geiger, A. Klaus. Manufacturing of Lightweight Components by Metal Forming.

11. Kristensson. Numerically produced forming limit diagrams for metal sheets with voids considering micromechanical effects. European Journal of Mechanics A/Solids 25 (2006) 13–23.

12. Daoming Li, Amit K. Ghosh. Biaxial warm forming behavior of aluminum sheet alloys. Journal of Materials Processing Technology 145 (2004) 281–293.