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Investigation on mechanical properties of aluminium 8090 alloy through room temperature rolling

Al-Li alloys are attractive for military and aerospace applications because their properties are superior to those of conventional Al alloys. Their exceptional properties are attributed to the addition of Li into the Al matrix. To develop an improved approach in achieving an excellent combination of high strength and ductility, the solutionized Al-Cu-Li plates were subjected to rolling at room temperatures to a reduction of 60%, 75% and amp; 85%. Rolling at room temperature produces a high density of dislocations because of the suppression of dynamic recovery, such high density of T1 precipitates enable effective dislocation pinning, leading to an increase in strength and ductility. The tensile properties of the age hardening Al 8090 alloy subjected to room temperature rolling (RTR) were investigated. The rolled and aged alloys were analyzed by using TEM, Vickers hardness analysis and tensile test as per ASTM standards. The strength and ductility of Al 8090 alloy of rolled samples are compared to unrolled samples.

Keywords: Tensile test, Vickers test, aluminium lithium alloy.

Review Introduction

Since the SPD (severe plastic deformation) techniques established in 1950s, there have been a lot of plastic deformation-based works conducted till date. Quite a variety of SPD process has also been developed in past few years in order to improve the mechanical properties of metals/ alloys resulting from grain refinement. In the past few decades, many SPD process such as multi-axial forging (MAF), equi-channel angular pressing (ECAP), high-pressure torsion (HPT) [6, 7], accumulative roll bonding (ARB) have been developed. These processes have shown a significant improvement in various mechanical properties such as yield strength, hardness, fatigue and fracture toughness. However, most of these processes involve sophisticated instrumentations, low production rates, sound expertise and design complexities. To obviate these limitations, a relatively simple technique is required that can produce ultrafine-grained (UFG) microstructure in metals/alloys without the need of sophisticated dies and expensive tooling. Room temperature rolling has been identified as a promising method for developing the UFG microstructure in metals/alloys without imposing much strain with high production rate. The latest development trends in the transportation industries, including the aerospace manufacture, are creating value by improving properties, fuel efficiency, enhanced recyclability and less environmental impact. It is well known that the weight reduction can meet the requirement for improving the performance and fuel efficiency. Besides, it is well proved that adding 1% lithium addition into aluminum alloys could provide 3% reduction of density and 6% increase of Young's modulus. The third generation Al-Cu-Li alloys has already established a leading role in a wide range of applications by military and aerospace industry due to its attractive mechanical properties, lower density and lower fatigue crack growth rate, etc. Although previous studies are comprehensive, there are still lack of the understanding of how textures and precipitations work together to affect the mechanical properties after different rolling reductions of the Al-Cu-Li alloy. In the present study, the transmission electron microscopy (TEM) and the high-resolution transmission electron microscopy (HRTEM) were used to observe precipitates, and the electron backscatter patterns (EBSD) was used to characterize textures of different rolling samples. Al 8090 alloy is a second generation heat treatable Al–Li alloy and was initially developed to replace the first generation of commercial aluminium–lithium alloys like 2014 T6, 2024 T3. Al–Li alloy (Al 8090) has been used in various aircraft like A340, EH101 helicopter, etc. as reported in various studies. These applications require high specific strength, good fracture and fatigue properties. In the past few decades, many researchers have shown their interest in aluminium–lithium alloy (Al 8090). Gregson and Flower investigated the effects of precipitations on the toughness of Al–Li alloy and found that formation of Al_3Li in Al–Li alloys decreases the toughness, while the formation of Al_2CuMg in quaternary (Al–Li–Cu–Mg) alloy increases the toughness. Liu et al. studied the effects of equi-channel angular pressing (ECAP) on fatigue behaviour of Al–Li 8090 alloy and reported a higher fatigue strength in ECAP

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samples compared to the heat-treated samples. Maria Rodrigues et al. compared the crack growth behaviour during fatigue loading of Al 8090 with traditional Al 2024 conventional cold rolled sheet also had been studied for comparison, which indicated that the ASR process is more beneficial to improve mechanical properties. A lot of researches have been done on the improvement of mechanical behaviour of Al–Li 8090 alloy by ECAP method, but the possibility of improvement in mechanical and fracture properties of Al 8090 alloy by room temperature rolling has not been explored so far. So, the present work is focused more towards the formation of UFG microstructure in Al 8090 alloy by room temperature treatment and to investigate the effects of RTR and post-deformation annealing on tensile and hardness properties of Al–Li 8090 alloy. Mechanical behaviour of Al 8090 is characterized by tensile, hardness testing and correlated further with its micro structural features with the help of optical, SEM and TEM observations.

2.0 Experimental procedure

2.1 Processing

For this study, Al 8090 alloy was procured from Mumbai, in the form of 80mm×40mm×25mm blocks. The composition of Al 8090 used in the present study is described in Table 1. The samples of dimension 80mm×40mm×15mm were prepared from Al 8090 sheets. These samples were then solution treated at 535°C for 2h followed by quenching in room temperature water to achieve equiaxed microstructure. These samples were then subjected to room temperature rolling treatment. The speed of the roller was 7 RPM for each pass. Thickness reduction of 40%, 60% and 90% was achieved through this method.

Table 1: Composition of aluminium – lithium alloy (Al 8090)

Alloy	Li	Cu	Mg	Si	Fe	Zr
8090	1.62	2.29	0.24	0.028	0.018	0.080

2.2 Sample preparation

Microstructure and phase present in the material were investigated by optical microscopy, TEM analysis for optical microscopy; the samples were initially polished by emery paper of different grit sizes and finished by polishing cloth. For TEM analysis, the thickness of the sample was reduced up to 100 lm with the help of mechanical grinding by emery paper. Then, samples were finally finished through ion beam milling and observed under Philips CM12 microscope operating at 120V. Tensile samples were made according to ASTM E8 subsize standard with a gauge length of 20 mm. Specification of tensile samples is shown in Fig.1.

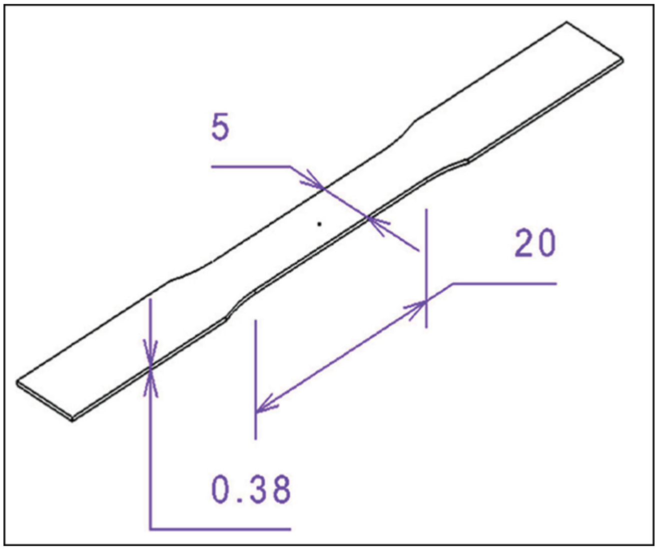

Fig.1. Specification of tensile specimen in mm

For tensile testing, minimum three samples were tested in each processing condition and average of three test results were used to plot stress–strain curve. Hardness was investigated through Vickers hardness testing machine under a load of 5 kgf with 15s dwell time. Three readings were taken from each sample at different locations. Average value of these readings was used to plot hardness data.

3.0 Results and discussion

The Vickers hardness of starting solution-treated material is 87HV as shown in Fig.2. After deformation at room temperature rolling up to true strain of 2.3 (90% reduction) and annealing at different temperatures, a trend in hardness was noticed, and hardness was found maximum (150 HV) at annealing temperature 150°C which gives an indication of precipitation during annealing, while decreased value of 95 HV was observed at annealing temperature of 350°C. This is owing to the fact that at lower temperature the work hardening effect is higher while with the increase in annealing temperature recovery effect comes into play due to which hardness falls abruptly from 140 HV (RTR + 200°C) to 101 HV (RTR + 250°C). The hardness becomes nearly constant on the samples annealed at elevated temperature (after 250°C). Hardness for the various processing conditions is listed in Table 1. Fig.3 shows the tensile properties (a) UTS and YS and (b) % elongation of room temperature-rolled (RTR) 8090 Al–Li alloy processed at various processing conditions. The tensile strength of the RTR alloy improved significantly as compared to the ST alloy. The UTS and YS of ST alloy were 275 and 192 MPa, respectively, which increase to 372 and 248 MPa, respectively, for samples processed by RTR. On post-rolled annealing at various temperatures ranging from 100 to 350°C, the gradual increase in the UTS and YS was observed up to the temperature of 150°C, while beyond 150°C these properties are significantly decreased and observed to be minimum for 350°C (Fig.3). In this work, RTR followed by annealed sample at 150°C has shown the maximum UTS (534 MPa) and YS (402 MPa). The mechanical properties of RTR and post-annealed alloy are listed in Table 2.

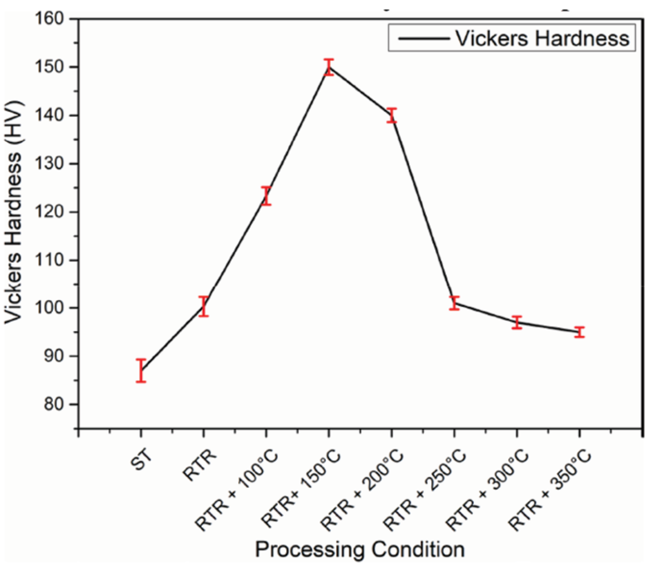

Fig.2: Variation of hardness of Al–Li 8090 alloy for different processed conditions

TABLE 2: MECHANICAL PROPERTIES OF AL–LI 8090 ALLOY AT VARIOUS

Processing condition	Vickers hardness, HV	Yield strength, MPa	Ultimate tensile strength, MPa	Percentage Elongation
ST	87	192	275	18
RTR	100.3	248	372	5.8
RTR+100	123.3	257	391	5.5
RTR+150	150	398	522	9.1
RTR+200	140	330	442	10.3
RTR+250	101	228	242	11.9
RTR+300	97	190	216	12.5
RTR+350	95	109	124	14

TEM results for various processing condition are depictedin Fig.4. In CR samples, the TEM micrograph shows elongated substructure and dislocation cells along the rolling direction. These substructures are well within the ultrafine regime (200 nm–500 nm). Linear intercept method is used to calculate the grain size of RTR material. At least 50 unique grains are considered for measuring grain size of RTR material by linear intercept method, and grain size of RTR material is observed to be 250 nm which confirms the significant grain refinement after rolling. In RTR samples annealed at 100°C, some of the dislocations get annihilated and transform into sub grain walls, and furthermore, the RTR 100°C samples show a small quantity of spherical d precipitate (shown by red-coloured arrow in TEM micrograph); needle-shaped precipitates (shown by blue-coloured arrow) can be seen distributed throughout whole sample (marked as yellow rectangle). Evolution of these phases in RTR 100°C samples can be seen in XRD results. CR 150°C samples show similar precipitate as seen in CR 100°C samples, but the volume fraction of precipitates is significantly higher than CR 100°C samples as seen from Fig.4c. It may be mentioned that secondary phase particles, which evolves up to 150°C (shown by yellow rectangles) start to dissolve at 200°C and this dissolution is continued as annealing temperature increases up to 350°C due to which volume fraction of precipitates decreases significantly at this temperature as seen in Fig.4d–g.

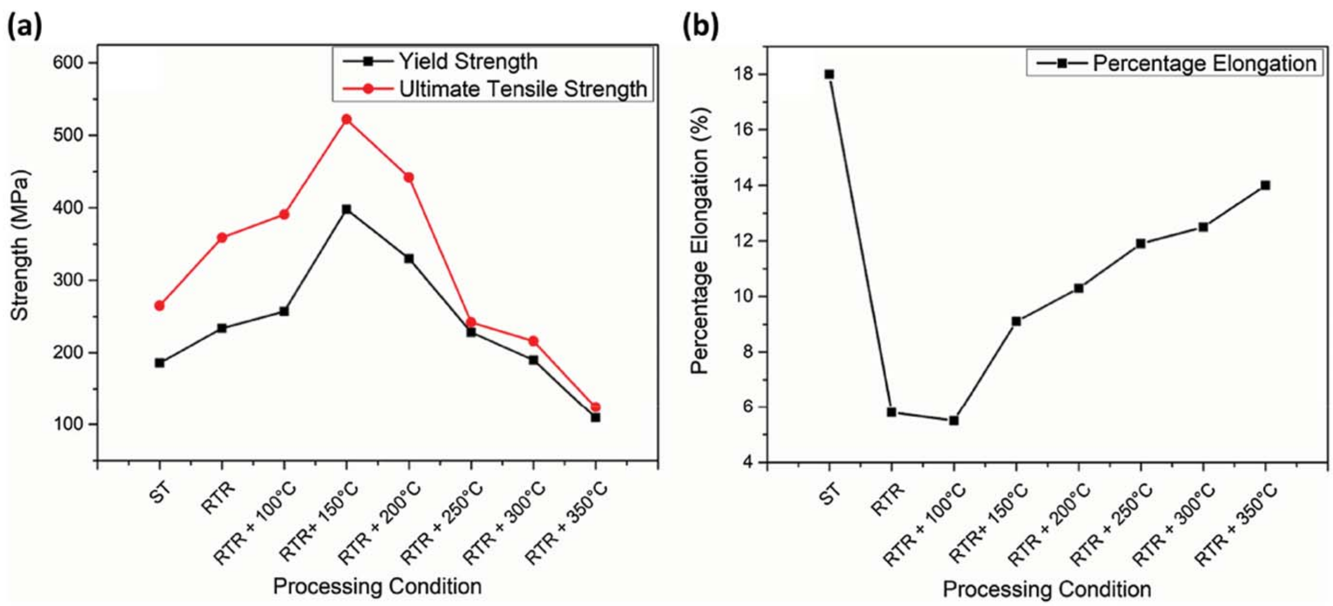

Fig.3. Variation of strength and elongation to failure of Al–Li 8090 alloy for different processed conditions (a) UTS and YS variation, (b) percentage elongation variation

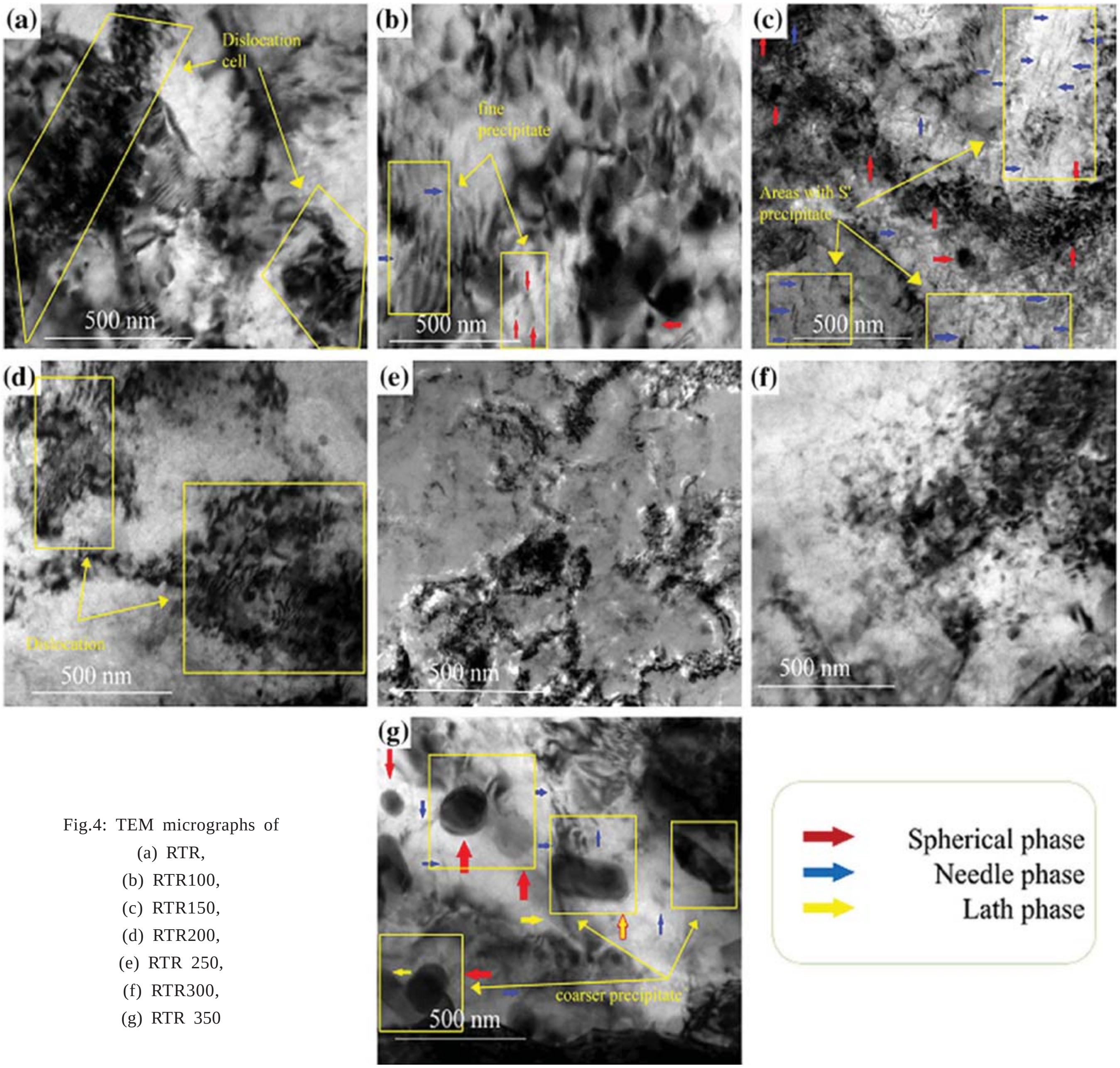

Fig.4: TEM micrographs of (a) RTR, (b) RTR100, (c) RTR150, (d) RTR200, (e) RTR 250, (f) RTR300, (g) RTR 350

4.0 References

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