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# Design And Fabrication of Sheet Metal Forming of AA 7075 Alloys & Their Studies On Microstructural And Mechanical Properties of Cold Rolled And Cryo Rolled Aluminum Alloys

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**Abstract**
Microstructure control always plays a key role in enhancing properties in high strength aluminium alloys. Designers of aircraft desire materials which will allow them to design lightweight, cost-effective structures which have the performance characteristics of durability and damage tolerance. Their needs are being met by new and emerging materials like aluminium alloys. Increase in fuel economy because of lighter weight structure is the driving force for aluminum alloys in the automotive market and cost is extremely important. Mechanical properties for automotive use also depend on the application, and corrosion resistance must. The desire for more efficient aircraft materials has fueled research of aluminum AA7075 alloys.

AA-7075 alloy samples were rolled at room temperature and at cryorolling (liquid nitrogen temperature) to 80 % thickness reductions and an attempt was made to evaluate the effect of rolling temperature on the microstructural changes and the variation in mechanical properties of these Al alloys. Williamson-Hall technique of X-ray diffraction line profile analysis (XRD) was performed to calculate structural parameters such as crystallite size, lattice strain and dislocation density. Cryorolled (CR) samples exhibited reduced crystallite size along with enhanced lattice strain and dislocation density than the RTR samples. Cryorolled samples also exhibited better hardness and strength compared to RTR samples and the enhanced properties are attributed to the higher dislocation density of the cryorolled samples due to suppressed thermal recovery. The formability, void coalescence of the above alloys was calculated in addition to the calculation of the mechanical properties. The mechanical properties were also correlated with microstructures and void coalescence parameters and it was observed that CR sample showed more necking percentage compared to RTR sample for rolling reductions of 80% and more formability was observed.

**Keywords:** Aluminium alloys; Precipitation hardening; Room temperature rolling Cryorolling; Tensile Properties; Structure-Property Correlation; Formability.

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## 1. Introduction

Aluminum alloys possess many important properties like high strength: weight ratio, good mechanical properties, formability and excellent corrosion resistance due to which they are treated as workhorses in many important sectors such as aerospace, automotive, marine and other industrial applications. Aluminium is treated as the steel of tomorrow. Though not capable of matching various varieties of steel in strength and toughness, Aluminium alloys have great advantage of strength: weight ratio and corrosion resistance. Aluminium and its alloys, from their first commercial development, were in widespread use as a lightweight structural material for various applications. For example, in the automotive industry, bodies have been developed and are used mainly for luxury cars, such as the Audi A8 the aluminium space frame, and some niche vehicles like the BMW Z8. This was attributed to the developed Al alloys that revealed enhanced strength-to-weight ratio, toughness and corrosion resistance.

In the last few years, various processing techniques which imposed of severe plastic deformation (SPD) on metals were developed. These SPD techniques lead to remarkable grain refinement, down to the sub-micrometer level, and thereby enhancing the strength of the metal. The formation of ultrafine grain (UFG) structure takes place by SPD methods providing large plastic deformation under high pressure and low temperatures. Among SPD techniques, Cryorolling (CR) results in the formation of UFG structured materials with relatively low plastic deformation (average grain size <1µm) with a high density of dislocations, being suitable materials for automotive and aerospace sectors (Valiev.et.al. (2000), Zheng et al. (2003)). The rolling of pure metals and alloys at cryogenic temperature suppresses the dynamic recovery and the density of the accumulated dislocations reaches a high steady level compared to room temperature. Higher density dislocations act as a driving force for the initiation of nucleation sites during annealing in sub-crystalline or UFG structures.

Many researchers reported that simultaneous improvement of both strength and ductility of CR materials received limited success except Cu. The mechanical behavoiur of AA-2219 alloy subjected to cryorolled and post annealing treatment was investigated by Shanmugasundaram et al.(2008) and they observed a significant improvement in YS (485MPa) and UTS (540MPa) in that alloy. Low temperature ageing heat treatment on CR age hardenable materials such as Al 7075 and Al 2024 alloy was carried out by Zhao et al.(2003) and Cheng et al.(2007), who obtained huge improvement of strength and density in both the materials.

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 can result in the failure of the material under different strain ratios. FLDs proposed as an important tool in the forming behavior of sheet metals and in the optimization of manufacturing, particularly in aerospace industries as reported by Campos et al. (2006). Kirstensson et al. (2006) reported a numerical study of micromechanical modeling affecting the formability. To

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evaluate the ductile fracture of Al alloy sheets, a ductile fracture criterion was proposed by Yu et al. (2007) and this proved an effective tool to predict the forming limit of Al alloys.

The main purpose of this work is to study the capacity and conditions of a metal during the formation and deformation processes. In metal forming operations, metals are subjected to three different strain conditions namely, biaxial stretching, plane strain and deep drawing. In biaxial stretching, thinning of sheet takes place and both principal stresses are tensile in nature. Biaxial stretching involves both principal stresses as tensile in both directions, whereas deep drawing involves tensile stress in one direction, and the compressive principal stress in the other direction, and is measured by a stretch test using a hemi-spherical punch.

## 2. Experimental Procedure

The AA7075 alloy was acquired from the M/s Hindalco Industries Ltd; Bangalore, India in the form of rolled sheets of thickness of 6 mm.

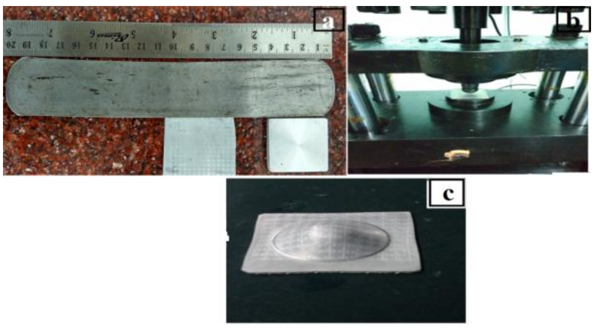

Fig. 1 Photograph of different processing conditions a) Sectioned for rolling from the casted billet, b) Sheet metal compression formability machine, c) Rolled at different conditions (Cold and Cryo-rolling) after formability.

A sample coupon for rolling at appropriate temperature was cut from the billet. The sample size of 35mm × 35mm × 6mm was used for rolling and followed by cold/cryo rolling Figure 1. The alloys were multi-pass rolled from 6 mm to 1 mm alloy was rolled at room temperature and cryo rolling (-190°C) with a reduction of 80% in thickness with constant strain rate (0.05 to 0.1). Cold rolled and cryo-rolled alloys were subjected to short annealing at 200°C for 10 min. The tensile test was conducted using Tinius Olsen, UK (Model: H50 KS) with the strain rate of 10-3/s as per ASTM standard. 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. Formability testing machine and sample used for test were calculated using the following empirical equations.

Strain (ε 1) = ((major diameter – 2.5 mm) / 2.5mm) x 100 ---- 1

Strain (ε 2) = ((minor diameter – 2.5 mm) / 2.5mm) x 100 ---- 2

## 3. RESULTS AND DISCUSSIONS

The present chapter discusses structure-property correlations of AA-7xxx alloy subjected to precipitation hardening behaviour and cryorolling. Initially, microstructural characterization of cryorolled (CR) as well as room temperature (RTR) alloys were presented. Further, mechanical properties such as hardness and tensile properties were evaluated. The metallurgical properties such as crystallite size, microstrain and dislocation density were calculated by XRD and correlated with mechanical properties. The above parameters were also used in evaluating the various strengthening mechanisms contributing to the overall behaviour of RTR and CR alloys samples rolled to 80 % reduction.

### 3.1 MICROSTRUCTURE ANALYSIS

The microstructural analyses were carried out on AA-7xxx alloy samples using Optical microscope. The micrographs a shown in fig. 2 from the micrographs, the of AA 7xxx alloys ascast condition microstructures shown in the finer grains were observed with the uniform distribution of finer precipitates are observed in the sample. On other hand, the coarser grain structure is witnessed with the thick grain boundary in the side due to the temperature gradient variation throughout the sample during the casting. This is attributed by fast heat dissipation at during metal casting. The structure consists of α-Al matrix and complex intermetallics $Al_6CuMg_4$, $CuAl_2$ and $MgZn_2$ and $Al_2CuMg$ by non-equilibrium solidification. The presence of intermetallic compounds is confirmed by X-ray diffraction studies (Fig. 3). The intermetallics are predominantly segregated along the grain boundaries which are brittle in nature and significantly affect the mechanical properties of casting. Microstructures of high alloy containing AA-7xxx series aluminium with different conditions (solutionised and aged) are shown in fig. 4.1. The equilibrium precipitates are dissolved in α-aluminium matrix during Solutionizing treatment. However, there are some undissolved precipitates in the matrix. The microstructure of peak aged alloy shows undissolved compounds and fine precipitates. The micrographs of cold rolling and cryo rolled alloy with 80% reduction in thickness. Fig. 2 shows AA-7xxx the micrographs of grains are elongated towards rolling direction and interestingly, the intermetallic precipitates are broken into finer scale and distributed in the matrix. The optical microstructure of cryo-rolled (-190˚C) AA-7xxx alloy with 80% thickness reduction are shown in fig 2. The distribution of intermetallic compounds are distribution uniformly throughout the matrix and their size is become by line in scale.

### 3.2 XRD Analysis

#### 3.2.1. Phase Identification

XRD analysis of the as cast sample was done by a Goniometer (Ultima3theta-theta gonio, under 40kV/30mA - X-Ray, 2θ / θ – Scanning mode, Fixed Monochromator). Data was taken for the 2θ range of 10 to 80 degrees with a step of 0.02 degree. In this XRD results peaks of aluminium and intermetallics. It is evident and confirmed that a phase of lithium is appeared in XRD patterns.

The structure consists of α-Al matrix and complex intermetallics $Al_6CuMg_4$, $Al_4Cu_3Zn$, $Al_2CuMg$, $MgZn_2$ and $Al_2Cu$ by non-equilibrium solidification. The XRD patterns are similar in all these conditions and showed the presence of T ($Al_6CuMg_4$ and $Al_4Cu_3Zn$), M (AlCuMg and $MgZn_2$) and S ($Al_2CuMg$) phases. The XRD peak of Al–12Zn–3Mg–2.5Cu alloy $MgZn_2$ it is evident from the XRD profile both soluble and insoluble compounds are seen. After rolling precipitates formed uniformly cold rolling and cryo rolling (-190˚C) evidence of XRD as shown in fig-4.

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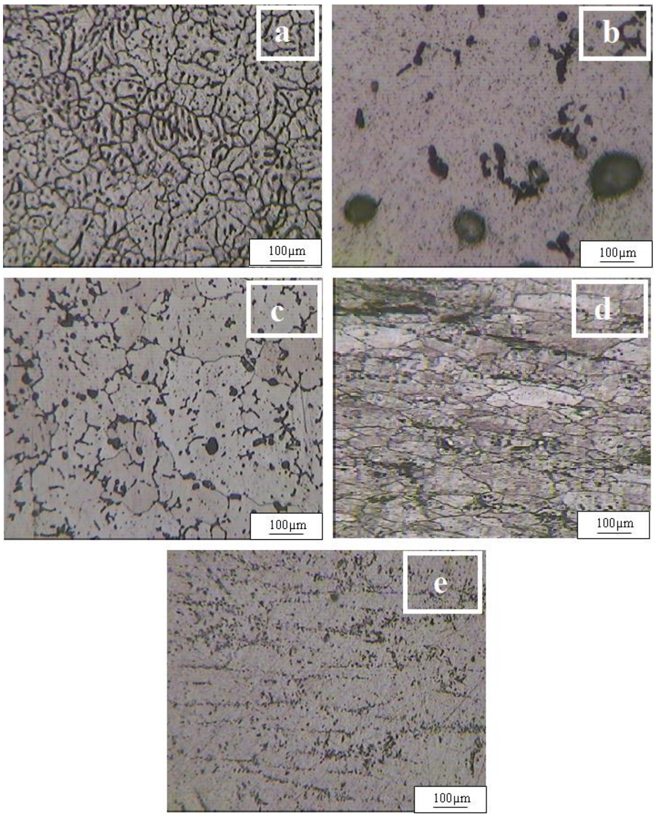


Fig. 2 Microstructure of AA-7xxx Aluminium alloys, a)Cast, b) Solutionized, c) Aged, d) Cold rolling, e) Cryo (-190˚C) rolling.

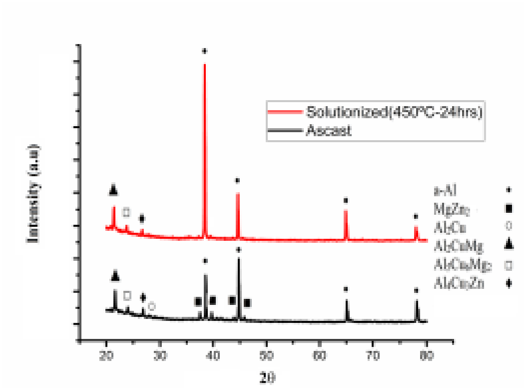


Fig. 3 X-ray diffraction patterns of AA-7xxx alloy at ascast and solutionized conditions

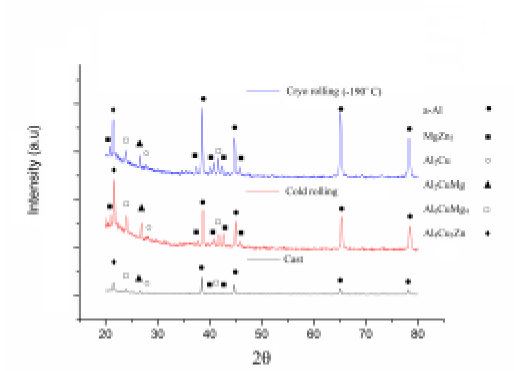


Fig.4. X-ray diffraction patterns of AA-7xxx alloy at cast, cold rolling and Cryo rolling

## 3. 3 MECHANICAL PROPERTIES

### 3.3.1. Micro hardness

Vickers hardness values for AA-7075 alloy in different conditions was plotted, which is shown in fig (5). Ascast value showed lower hardness values due to its inhomogeneous structure shown in Table - 1. Aged condition sample exhibited higher hardness values than that of solutionized condition due to increased dislocation cell structure and precipitation hardening strengthening and solutionized sample shows lower hardness comparing ascast and aged samples because of after solutionized at different temperatures and with respected time dissolves precipitates within the matrix.

The comparison of micro hardness values for the base material and the rolling materials shown in fig (5). It is observed that the rolling operation has increased the hardness values of deformed material from that of the solutionized material by 80% reduction of thickness rolling at cold rolling and cryogenic temperature causes the accumulation of dislocations and reaches higher density level than sampled at room temperature due to suppression of dynamic recovery .As rolling direction increase grains become fine .So grain

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boundary strengthening is more for high stained sample .So that 80% reduced samples have more hardness values than samples at all the conditions.

The comparison of micro hardness values for the AA7075 exhibit higher hardness values of AA-7xxx material cause of adding elements of Zn and Mg to form the precipitates ($Al_2Cu$ & $MgZn_2$) and second phase particle ($Al_2CuMg$ & $Al_5Cu_6Mg$).

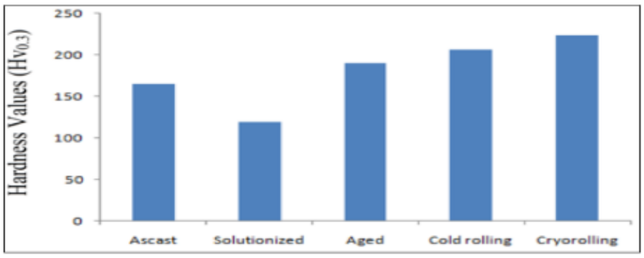


Fig 5 Hardness details of AA7075 material

**3.3.2. Tensile properties**

Table: 1. Tensile properties of AA-7075 alloy

| Conditions | $(Hv)_{0.3}$ | UTS (MPa) | %Elongation |
|---|---|---|---|
| As cast | 165 | 350±10 | 3.8 |
| Solutionized | 120 | 265±10 | 7 |
| Aged | 190 | 580±10 | 6 |
| Cold rolling | 206 | 620±10 | 5 |
| Cryo rolling | 224 | 687±10 | 4.5 |

Stress – strain curves of AA-7075 alloy with different conditions are shown in fig. (6 & 7). The ultimate tensile strength (UTS) of AA-7075 alloy, cast, solutionized, aged, cold rolling, and cryo rolling alloy is 350MPa, 265MPa, 580MPa, 620MPa and 687MPa the elongation is 3.8%, 7%, 6%, 5% and 4.5% respectively (Table-1). Cast alloy has resulted good strength by solid solution and lower ductility by micro-segregation of complex intermetallics along the grain boundaries. Precipitation hardened aluminum alloy exhibits approximately 40% increment in UTS than that of cast alloy with (6-8) % ductility. The increment in strength and ductility after ageing are attributed by combined effect of solid solution, precipitation hardening and dispersion hardening. The strength and hardness of aged alloy are better than that of cast and solutionized alloy. During solutionizing and quenching of AA-7xxx alloy, the solute atoms are getting dissolved and the internal strain from the alloy is also completely relieved. The effect of ageing temperature on structural transformation and increasing mechanical properties is not appreciated due to the strong pinning effect of insoluble compounds.

The ultimate tensile strength (UTS) of the cast alloy and the rolled material (80% reduction) are compared in AA-7xxx engineering stress-strain graph are shown in fig (6 & 7). Cast alloy has resulted good strength by solid solution and lower ductility by micro-segregation of complex intermetallics along the grain boundaries. Cold rolling material exhibited enhanced high tensile strengths by increased ductility, which is attributed to increase stored in the form of large dislocation density due to rolling. The improvement in strength values are proportional to increased rolling reductions due to proportionate increase in dislocation density induced in material and grain refinement. The combination of cold rolling and cryorolling on the mechanical properties of AA-7xxx alloy has shown an improved strength and increase in percentage elongation (30%) as compared to the cast sample. The cryorolling samples (-

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190˚C) shows a large enhancement in the higher strength as compare to cold rolling samples show in above Table-1. The enhancement in the strength of cryorolling samples is mainly by the combined effect of high dislocation density, partial grain refinement, solid solution strengthening and nano size fine precipitates.

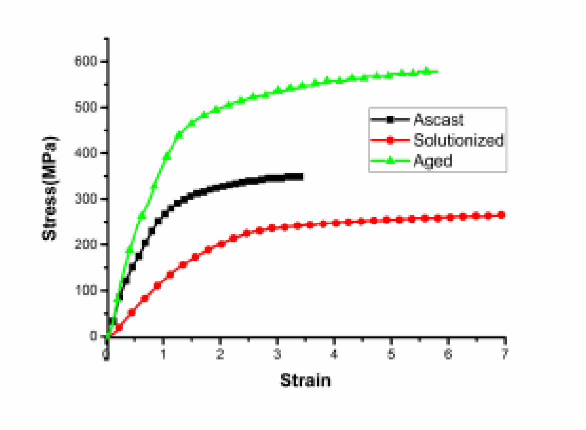


Fig. 6 Stress-strain curves of AA-7xxx alloy at different condition.

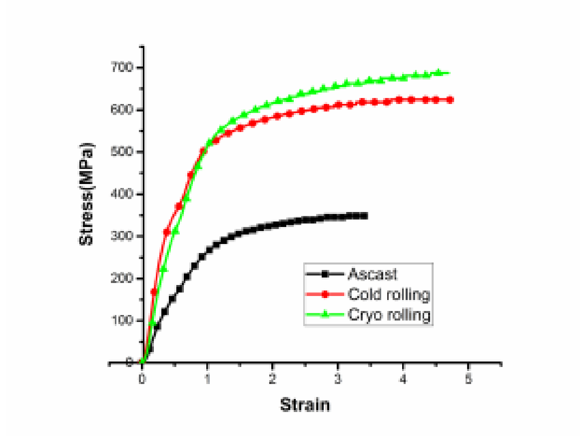


Fig. 7 Stress-strain curves of AA-7xxx alloy at different condition.

### 4.4 Fracture Analysis

SEM fractographs of tensile tested AA-7xxx alloy (cast, solutionized, aged cold rolling and cryo rolling conditions) are shown in Fig. (8). Fractographs of as cast, solutionized and aged alloy show mixed mode of fracture. The dimple size is reduced in aged condition, cold rolling and cryo rolling conditions. Some regions of the fractographs exhibit well developed primary and secondary dimples; however, cleavage facets are observed in some other regions. Ultra-fine dimples are also noticed caused by the fine precipitates, mainly $Al_2Cu$, $MgZn_2$ shown in AA-7xxx.

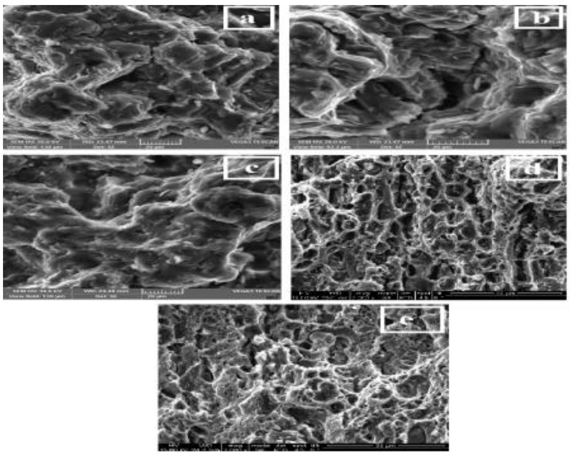

Fig. 8 Fracture surface of AA-7xxx alloys, a) Cast, b) Solutionized, c) Aged, d) Cold rolling e) Cryorolling.(-190˚C)

### 4.5 FORMABILITY

The forming and the fracture limit diagrams of AA-7xxx alloy sheets submitted to cold rolling and cryo rolling at different rolling reductions were presented in fig.4.8.

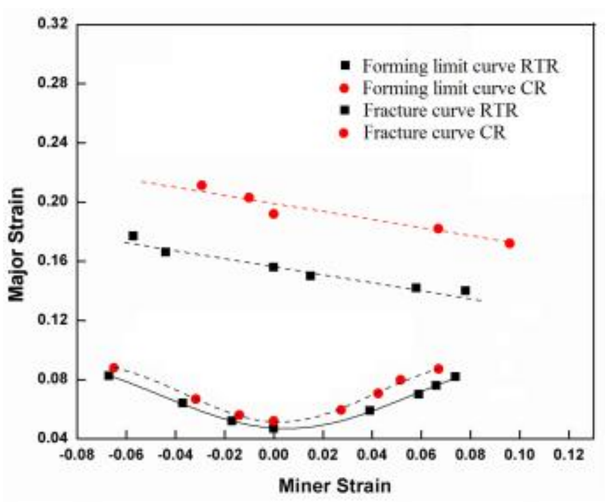

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Fig. 9 Forming limit diagrams and fracture curves for AA-7xxx at Cold rolling and Cryo rolling conditions

Table 4.2 Limit strain values for different rolling conditions

| Condition | | Limit Strain in Percentage | | | | |
|---|---|---|---|---|---|---|
| | | T-C Region | | PS Region | T-T Region | |
| | | Major Strain | Minor Strain | Major Strain | Major Strain | Minor Strain |
| Forming Limit Diagram (FLD) | RTR | 7 | -5 | 4 | 7 | 5 |
| | CR | 8 | -5 | 5 | 8 | 5 |
| Fracture Limit Curve(FRC) | RTR | 21 | -5 | 20 | 19 | 5 |
| | CR | 17 | -5 | 16 | 15 | 5 |

It was observed from the Fig.4.2 that cryorolled AA-7xxx alloy samples exhibit high percentage of necking percentage irrespective of the forming region tension- compression (T-C), plane strain (PS) and tension- tension (T-T). In T-C region, AA-7xxx alloy of cryo rolling temperature rolled condition possesses a compressive minor strain of 5% and maximum major strain of 8%. In plane strain condition, the limiting major strain offered by it is about 5%. For T-T strain condition, minor strain offered by it is 5% and the maximum major strain offered is 8%. Cryo rolling sheets show better formability.

In the case of fracture curve, for cryorolled AA-7xxx alloy exhibits major strain of 17 % and a compressive minor strain of 5% was observed in the T-C region. However, the major strain value of 16 % for PS region and 15 % was observed in the case of T-Tat a minor strain of 5%. For the case of cold rolling condition the maximum major strain values are 21%, 20% and 19% were observed for T-C, PS, T-T regions respectively. The cold rolling sheet exhibits better formability compared to cryo rolling sheet at 80% rolling reduction. The high degree of plastic deformation was observed in these regions may be due to high degree of cross slip during cryo rolling samples of 80% were having more dislocation densities and less crystallite sizes favoring the less formability.

**Conclusions:**

1. Cryo rolling samples exhibited increased mechanical properties compared to cold rolling samples, which is due to their enhanced dislocation density and lattice strain and reduced crystallite size as obtained from calculations of XRD.
2. The cold rolling samples exhibits better formability than that of the cryo rolling samples At both rolling reductions and samples with 80% rolling reduction exhibits more formability.
3. The cast alloys showed coarse intermetallic expound which are segregated along the grain boundaries.
4. In order to improve the mechanical properties, such as tensile strength,elongation, etc. precipitations hardening
5. Room temperature rolling results fragmentation of coarse intermetallics into finer scale and distribute all the precipitates throughout the α-aluminium matrix
6. Both cryorolled and room temperature rolled AA-7075 alloy sheets exhibits fair formability. The formability is higher in T-T strain region compared to T-C or PS regions. A combination of fine and coarse grains in the form of elongated microstructure help in improving the necking ductility. The high necking strain during T-C and plane strain region is due to more cross slip. The formability properties of cold rolling and cryorolling temperature rolled samples are

correlated with micro structures and mechanical properties.

7. Fractographs of AA-7075 alloy in different processing conditions reveal a mixed mode of fracture. Ultra-fine dimples are noticed, caused by the precipitation of a mixture of fine particles, mainly Al2Cu and MgZn2.

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