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Characterization Of Mechanical Properties Of Cryorolled Aa8011 Alloys Sheet

[1][2] Manish N Parmar, [3][4*]A.B.Dhruv

[1] Research Scholar_Gujarat Technological University,
[2]Assistant Professor Mechanical Department Vishwakarma Government Engineering College, Chandkheda, Ahmedabad
[3] Research Supervisor, Gujarat Technological University, Ahmedabad
[4] Professor in Mechanical Engineering Department, Government engineering College, Patan

Abstract: The mechanical properties of sheets made from the AA8011 alloy were cryorolled, annealed, and cold rolled in this work. Cold rolled and cryorolled annealed sheets were compared. Cryorolling is one of the essential severe deformation techniques needed to produce sheets with exceptional strength. From three millimeter-thick sheets, this alloy was cryorolled in numerous passes to a final thickness of one millimeter. A rapid annealing at 200°C for 45 minutes after cryorolling would result in a good balance of strength and ductility, according to study on the effect of annealing temperature and time on hardness.
Keywords: aluminium alloys, cold rolling, cryorolling, mechanical properties

1. Introduction

Gopi et al., 2012 [1]Cryogenic rolling, also known as cryorolling, is one technique for generating nanostructured bulk materials from their bulk counterparts at cryogenic temperatures, or around -196°C for liquid nitrogen. The majority of these procedures need sizable plastic deformations (strains significantly higher than unity). Due to its low density, ideal plasticity and strength, and ease of surface processing, pure aluminium and aluminium alloys are now frequently used in the construction, packaging, transportation, electronic, mechanical and electrical manufacturing, aerospace, and petrochemical industries[2]. Feyissa et al.,2017[3]The microstructure, mechanical characteristics, and formability of cryorolled and annealed AA5083 are examined in this paper. Characteristics of alloy sheets have been examined, and they have been contrasted with cold-rolled and annealed sheets. Cryorolling was used to reduce sheets of this alloy that were five millimeters thick to a final thickness of one millimeter.(With a real strain of 1.6, the reduction is 80%). Hardness has been impacted by annealing time, temperature, and study, it was discovered that a quick annealing at 275ºC for 15 minutes would produce a an excellent balance between ductility and strength. Microstructural analysis revealed that the bimodal grain structure of the cryorolled and brief annealed samples is what gives them greater mechanical performance than cold rolled sheets. The limit strains of cryorolled sheets have been discovered to be approximately equal to conventional cold rolled and annealed sheets in all modes of deformation, according to the experimentally obtained forming limit diagrams. The distribution of strains has not revealed any significant differences either. This work proves unequivocally that AA5083 alloy sheets may be cryorolled, followed by a brief annealing with a bimodal grain structure, and used for sheet metal forming applications with higher strength and toughness than traditional sheets without suffering any formability loss. Satish et al.,[4]Cryorolling is a severe plastic deformation (SPD) process used to obtain ultrafine-grained aluminum alloy sheets along with higher strength and hardness than in conventional cold rolling, but it results in poor formability. An alternative method to improve both strength and formability of cryorolled sheets by warm forming after cryorolling without any post-heat treatment is proposed in this work. The formability of cryorolled AA6061 Al alloy sheets in the warm working temperature range is characterized in terms of forming limit diagrams (FLDs) and limiting dome height (LDH). Strain distributions and thinning in biaxially stretched samples are studied. Hardness of the formed samples is correlated with ultimate tensile strength to estimate post-forming mechanical properties. The limit strains and LDH have been found to be higher than in the case of the conventional processing route (cold rolled, annealed and formed at room temperature), making this hybrid route capable of producing sheet metal parts of aluminum alloys with high strength and formability. In order to combine the advantages of enhanced formability and better post-forming strength than the conventional cold rolled and annealed sheets, warm

forming at 250°C has been found to be suitable for this alloy in the temperature range that has been studied. Although cryorolling produces ultra-fine grained aluminum alloy sheets with higher strength and hardness than conventional cold rolling, it has poor formability. Cryorolling is a severe plastic deformation technique. In this work, a different approach to improving the strength and formability of cryorolled sheets without using any further post-heat treatment is suggested. Cryorolled AA6061 Al alloy sheets' ability to be formed in the warm working temperature range is described by forming limit diagrams and restricting dome height. In biaxially stretched materials, the distribution of strain and thinning are investigated. To calculate the mechanical properties after forming, the ultimate tensile strength of the formed samples is connected with their hardness.Rao et al.,[5] Due to its high strength and excellent ductility, an ultrafine grained (UFG) structure created in precipitation hardenable aluminum alloys through cryorolling, suppression of dynamic recovery, and low temperature aging has attracted a lot of study attention. To explore the impact of annealing on the microstructure and mechanical properties, Al 6061 alloy was solution treated, cryorolled up to an effective true strain of 2.6, and then exposed to annealing at temperatures between 150ºC and 350ºC.Transmission electron microscopy (TEM) and X-ray diffraction (XRD) techniques were used to examine the evolution of microstructure and precipitates. To assess how annealing affected the mechanical properties, Vickers hardness and tensile tests were run at room temperature. It was shown that annealing at 150ºC increased ductility and strength, and that annealing at higher temperatures (200–350ºC) reduced hardness and strength while increasing ductility. The precipitation of the metastable phase β" is what causes the strength to significantly increase during low temperature annealing (150ºC). It compensates excessively for the softening brought on by the recovery effect, which resulted in a decrease in hardness. The cryorolled Al 6061 alloy with UFG structure was discovered to be thermally stable up to temperatures of 250ºC with a modest coarsening of the grain. The TEM tests showed that second phase Mg_2Si particles are actually pinning the grain boundaries at this temperature because of the Zener drag effect. Due to the material's heterogeneities, a duplex structure developed during annealing at temperatures of 150 and 200ºC. Observations of abnormal grain development were made following annealing at high temperatures (300ºC).Singh et al.,[6] This article examined the effects of rolling at liquid nitrogen temperature and annealing on the microstructure and mechanical characteristics of Al 5083 alloy. Al 5083 samples that have been cryorolled exhibit notable increases in strength and hardness. For the 30% and 50% cryorolled samples, the ultimate tensile strength rises to 340 MPa and 390 MPa, respectively. The cryorolled materials with reductions of 30% and 50% were tested for Charpy impact at temperatures ranging from -190°C to 100°C. Through an increase in yield strength and a decrease in ductility, it has been found that increasing the percentage of samples reduced during cryorolling significantly reduces impact toughness at all temperatures. Samples that have undergone cryorolling and annealing exhibit a notable increase in impact toughness due to recovery and recrystallization. The average grain size of the 50% cryorolled sample (14 m) is found to be finer than that of the 30% cryorolled sample (25 m) after being annealed at 350ºC for 1 h. The investigation of broken surfaces by scanning electron microscopy (SEM) reveals a fibrous structure with extremely small dimples in cryorolled samples, which corresponds to the brittle fracture mechanism, and a large-size dimpled morphology in the beginning material. Krishna et al.,[7] Cryorolling's impact on the mechanical characteristics of the AA5083 alloy was studied. Additionally, the impact of temperature and rolling strain on the Portevin-Le Chatelier phenomenon that occurs in aluminum alloys with magnesium as a significant component was investigated. In-depth research was done on the microstructure evolution of the AA5083 alloy at room temperature (RT) and cryorolling (LNR), as well as how it affected the alloy's mechanical properties. The findings demonstrated that as the rolling reduction was increased, the hardness values rose.LNR had no appreciable impact compared to RT rolling. In comparison to LNR circumstances, deformation-induced precipitation particles of Al_6Mn during RTR had improved mechanical characteristics. Due to decreased adiabatic heating for samples under LNR circumstances, very little precipitation was seen. Manganese that was present in the test sample in excess of its solid solubility limit may have had an impact on how the AA5083 alloy material behaved during rolling. The Portevin-Le Chatelier effect was clearly seen, and it was noted that the critical strain for the PLC effect's start decreased with smaller grain size and rising dislocation density. Taye et al.,[8]Due to their excellent corrosion resistance and high strength to weight ratio, Al-Mg alloys are widely employed in the aerospace and marine industries. One of the crucial severe deformation processes to create sheets with great strength is cryorolling. However, the car industry cannot use cryorolled sheets because of their

poor formability. The formability of cryorolled AA5083 alloy sheets was characterized in the current work. Mechanical properties were examined between sheet samples that had been cryorolled and cold rolled with an 80% reduction in thickness. Through a limiting dome height test, formability in biaxial stretching mode was determined. On cryorolled AA5083 alloy samples, partial annealing between 150°C and 300°C was carried out to increase formability without noticeably reducing strength. The ideal heat treatment temperature for producing a suitable balance of strength and formability was found to be between 200 and 250°C.

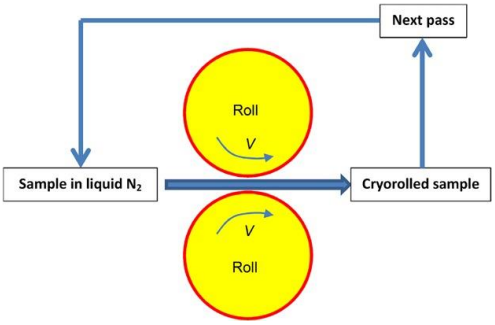


Figure.1: A schematic showing conventional rolling and cryogenic rolling.

Because of its ability to be lighter than steel and the potential to do so, aluminum alloys have played and continue to play a significant part in the growth of the automobile industry.

Cryorolling is a helpful low-temperature rolling technology that can increase strength and ductility, providing more opportunity to reduce weight in even more applications where strength is crucial. Due to their lower density than steel, light metals now play a significant part in the development of the automotive sector. Light metals are now employed more frequently in a variety of products, including engine blocks, chassis, rims, etc. There are certain drawbacks, though. In general, light metals like magnesium and aluminum are not as strong as steel, and therefore have only been used in components where the thickness of the material can be raised to accommodate the required strength and rigidity or when strength is not a crucial concern.

Due to its high strength to weight ratio and resistance to corrosion, aluminum alloys are now used more frequently in the automobile sector, which helps to increase fuel efficiency and lower CO2 emissions. Lower strength and formability compared to typical steels is one of their main shortcomings. It is a significant challenge to replace steel with aluminum alloys in existing safety-critical structural components like bumper systems, door intrusion beams, and B pillars in automobiles. As a result, emphasis has increased on producing aluminum alloy sheets with high strength and good formability.

Many severe plastic deformation methods are employed to produce ultrafine grain structured materials. The only one of these methods, cryogenic rolling, is appropriate for mass-producing thin sheets with an ultrafine grain structure continuously. Rolling the sheets at cryogenic temperatures produces typically very substantial thickness reductions (70-90%) while achieving a high degree of grain refinement. When compared to traditional room temperature rolling, the cryorolling technique results in a significant increase in strength and hardness due to the suppression of dynamic recovery, an increase in dislocation density, and grain refinement. Cryorolling, however, has some significant drawbacks, including a significant loss of ductility and formability. Despite their increased strength, these sheets in their as-cryorolled condition are not appropriate for the sheet metal industry.

A straightforward low-temperature rolling technology called cryorolling uses liquid nitrogen to keep the temperature low. High strength and ductility combinations can be achieved at cryogenic temperatures by a special mechanical deformation method. The material cools during the cryorolling process, its molecular structure compresses, and dislocations become entangled close to the grain boundaries. Rolling at a cryogenic temperature reduces dynamic recovery in the materials, increasing the density of accumulated dislocations to a higher steady state level, which in turn drives the development of sub-microcrystalline or ultrafine grain structures (UFG) during the subsequent annealing process.

A two-high rolling mill is used in the schematic diagram of the standard cold rolling and cryogenic rolling operations in Figure 1. The sheets are rolled at room temperature through a number of passes in conventional cold rolling (CCR) to get the desired final thickness.

2. METHODOLOGY

2.1 Material selection

We bought 3mm thick AA8011 metal sheets in the H116 condition. Following spectroscopic investigation, the chemical makeup of the alloy is shown in Table.1.1 in weight%.

Table 1 Composition of alloying elements in weight% of AA8011

	Aluminum (Al)	Chromium (Cr)	Copper (Cu)	Iron (Fe)	Magnesium (Mg)	Manganese (Mn)	Silicon (Si)	Titanium (Ti)	Zinc (Zn)	Nickle (Ni)
AA8011	98.58	0.002	0.020	0.66	0.012	0.061	0.63	0.020	00	0.003

Their chemical makeup is listed in Table 1. Using a 4 high rolling mill and 200mm diameter work rolls at 50rpm, samples of these sheets with dimensions 200mm x 200mm were cryorolled and cold rolled. The thickness was eventually lowered to 1mm. It was accomplished over a number of passes, with a reduction of between 15% and 20% in each pass. After each pass, the roll gap was corrected using the digital roll gap display. The actual experimental setup and the cryorolling rolling mill are shown in Figure.2. Rolled sheets were low temperature annealed to produce a stable microstructure.

(a) Rolling mill and overall experimental setup used for cryorolling | **(b) cryorolling**

Figure.2: (a) Rolling mill and overall experimental setup used for cryorolling; (b) cryorolling

In cold rolling, we needed four passes to reduce a sheet of 3 mm 8011 al alloy to 1 mm thick. We reduce the thickness by roughly 25% with each pass.

When we first started cryorolling, we submerged 3mm-thick Al alloy sheets in liquid nitrogen for a sufficient amount of time to achieve the required cryogenic temperature (-196^{0}C). The required dipping time was calculated as 40–45 minutes utilizing a digital temperature measurement pistol to determine the amount of temperature. Cryorolling took six passes to shrink a 3mm thick sheet of 8011 Al alloy to 1mm thick, and we submerged our specimen for 10-15 minutes during each pass. We reduce the thickness by roughly 15–17% in each iteration.

2.1Cryorolling and Heat treatment

High thickness reductions are necessary to achieve ultra-fine grain structure, so a 3mm thick sheet sample measuring 200mm x 200mm was rolled using a 4 high rolling mill at 80% reduction while under

cryogenic conditions to create final sheets that were 1mm thick. The first samples were also cold rolled at room temperature to assess the rise in strength and hardness.

Aluminum alloys strengthened by cold or cryorolling lose some of their ductility, making them unsuitable for forming. Therefore, a suitable heat treatment was applied to the cold rolled (CLR) and cryorolled (CYR) sheets to increase ductility without considerably lowering strength. Recovery annealing, or partial annealing, was carried out for 40 minutes at a temperature between 200 and 250°C (below the recrystallization temperature) to achieve the required balance of strength and ductility.

3. Characterization of Mechanical Properties

3.1 Hardness

As per ASTM E18-22 standard, cold rolled and cryorolled samples were subjected to hardness tests using Vicker's microhardness testing equipment. Hardness values were recorded at three distinct points with an applied load of 100 g and a dwell time of 15 s. After 3mm to 1mm reduction for both cold rolled and cryorolled samples, hardness has been calculated as a function of annealing time and temperature in order to identify the best annealing conditions.

Table 2. Hardness of cold rolled and Cryorolled samples of AA8011 alloy

Conditions	**Hardness in HV1**			**Average**
Cold Rolled+ Annealed	49.2	55.2	55.8	53.40
Cryo Rolled+ Annealed	**61.0**	**64.1**	**59.0**	**61.36**

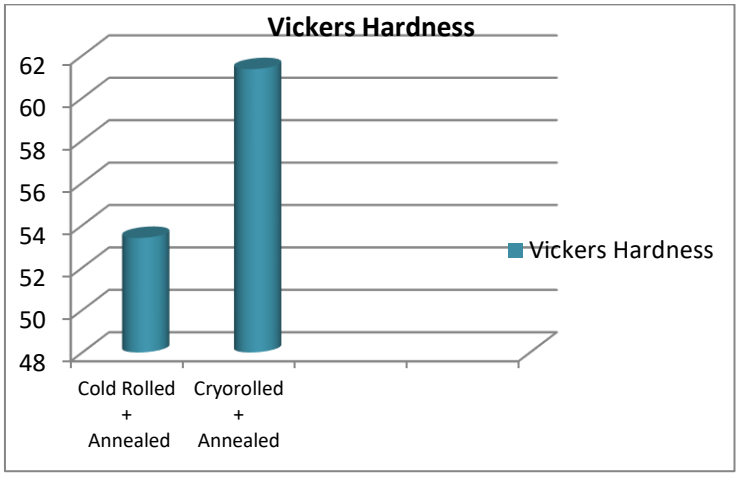


Figure.3: Variation of hardness of AA8011 alloys for cold rolled and cryorolled conditions

The hardness values in the rolled condition are also shown for comparison. The hardness ratings of cryorolled material are 15% higher than those of cold rolled sheets after a 3mm to 1mm reduction. The increased hardness of cryorolled sheets is caused by a higher dislocation density.[9] Cryogenic rolling of pure metals and alloys prevents dynamic recovery and increases the density of accumulated dislocations with the number of passes. The hardness decreased as annealing temperature increased, with a greater rate of reduction occurring beyond 200°C[10].

3.2 Surface Roughness

Six separate locations can be used to measure the surface roughness of 1mm 8011 aluminum alloys that have been cryorolled and cold rolled. For cold rolled 1mm 8011 aluminum alloys, the roughness values are 1.162, 0.892, 0,933, 1.014, 0.792 m at various places, and 0.959 m as the final average. For cryorolled 1mm

8011 aluminum alloys, the roughness values are 0.381, 0.861, 0.564, 0.246, and 0.491 m at various places, with 0.509 m serving as the final average value.

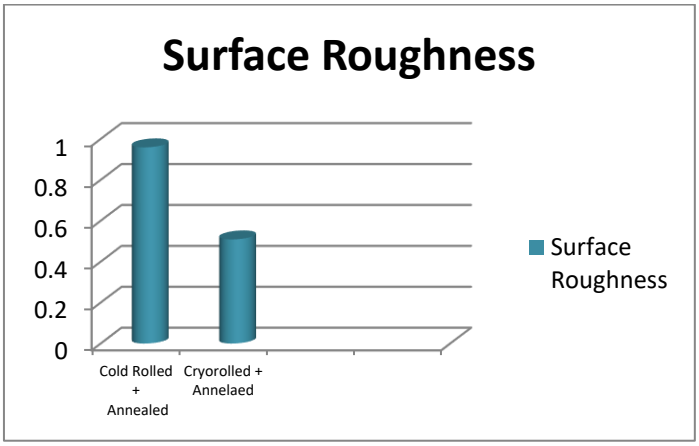


Figure.4: Variation **of surface roughness of AA8011 alloys for cold rolled and cryorolled conditions**

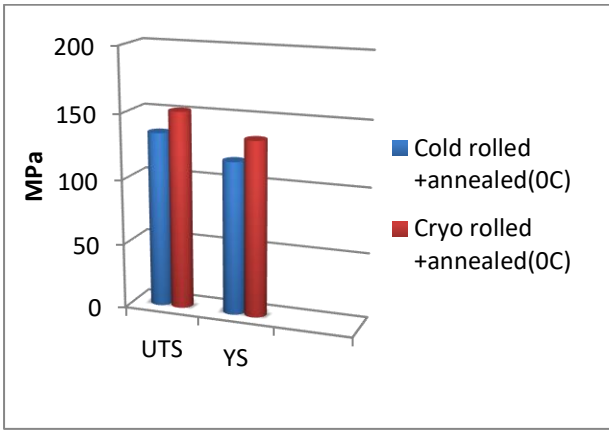
3.3 Tensile Properties

Tensile samples of CLR and CYR sheets were examined at room temperature on an Instron machine with a constant crosshead speed of 2.5mm/min. According to ASTM Regulations ASTM E8/E8M-22, the specimens were created utilizing laser cutting. The load elongation information obtained from the tensile tests on the cryorolled and cold rolled specimens was used to plot engineering stress-engineering strain curves. The standard tensile characteristics, including YS, UTS, and percentage elongation, were also computed using the recorded data. Depending on the rolling direction, both normal to and within the sheet plane, sheet metals have different characteristics. This characteristic, called anisotropy, results from the crystalline texture of the rolled sheet metals.

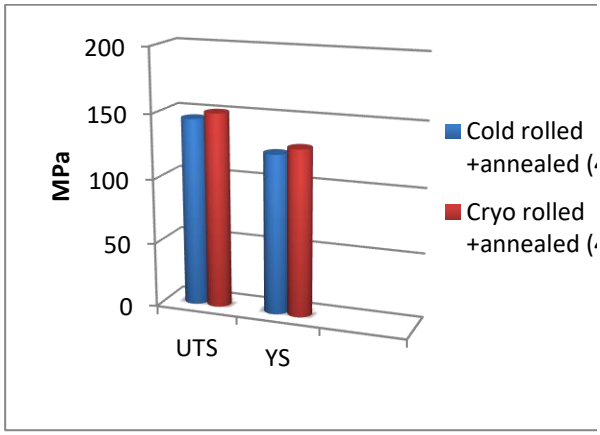
The sheet is dislocated heavily in its rolled-out state. It is shown that dislocation density grows even more when processing temperatures are decreased to cryogenic levels because dynamic recovery is hindered. This resulted in enhanced strength and hardness as compared to cold rolling in all three test orientations (0°, 45°, and 90° to rolling direction), as shown in Table 3.

Table 3. Tensile properties of Cold rolled and Cryorolled samples of AA8011 alloy

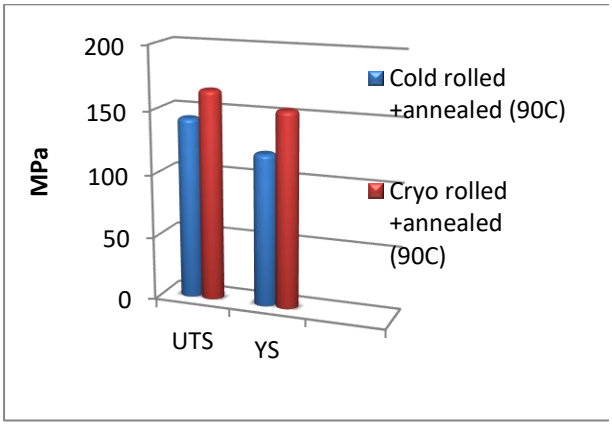
Conditions	**Orientation with respect to Rolling Direction**	**YS (N/mm^2)**	**UTS (N/mm^2)**	**Total Elongation (%)**
Raw Material	--	94.268	98.175	1.20
Cold Rolled+ Annealed	0º	117.507	134.613	2.84
	45º	123.472	145.234	3.44
	90º	120.114	143.131	3.06
Cryo Rolled+ Annealed	0º	**134.648**	**151.761**	**3.72**
	45º	**128.857**	**150.722**	**3.94**
	90º	**154.161**	**165.762**	**3.98**



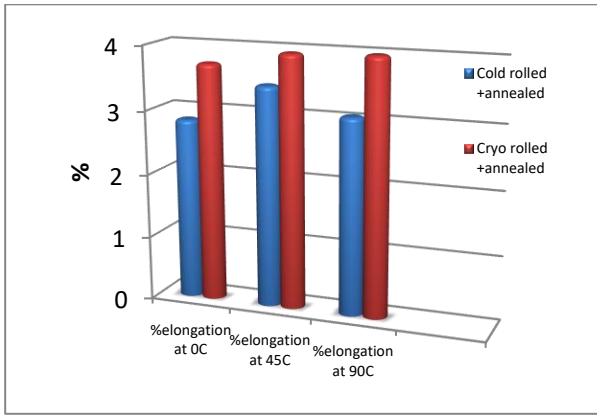
Comparision of UTS and YS for cold rolled and cryorolled sheet at 0ºC with respect to rolling direction



Comparision of UTS and YS for cold rolled and cryorolled sheet at 45ºC with respect to rolling direction

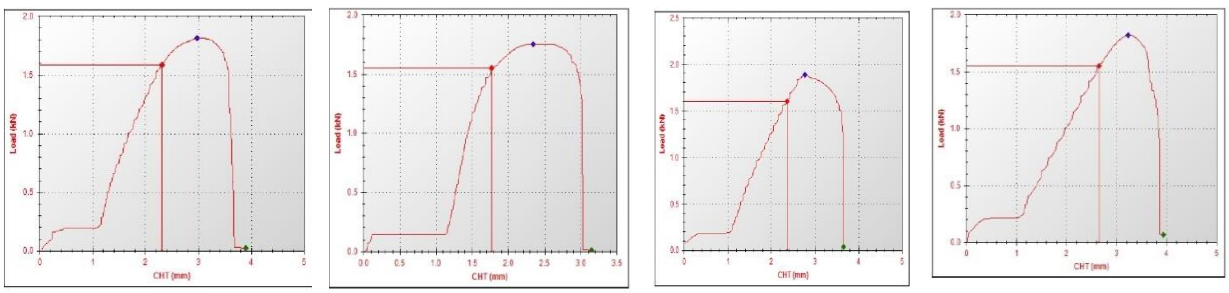


Comparision of UTS and YS for cold rolled and cryorolled sheet at 90ºC with respect to rolling direction

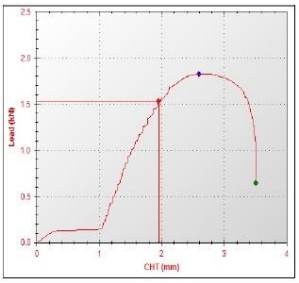


Comparision of %Elongation for cold rolled and cryorolled sheet at 0ºC , 45ºC and 90ºC with respect to rolling direction

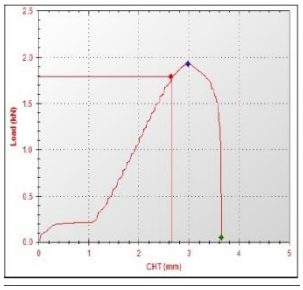
Figure.5: Variations in UTS, YS and elongation of the cold and cryorolled samples at at 0ºC , 45ºC and 90ºC with respect to rolling direction.



Load vs CHT at for cold rolled and cryorolled sheet at 0ºC with respect to rolling direction



Load vs CHT at for cold rolled and cryorolled sheet at 45ºC with respect to rolling direction



Load vs CHT at for cold rolled and cryorolled sheet at 90ºC with respect to rolling direction

Figure.6: Variations in Load vs CHT of the cold and cryorolled samples at at 0ºC , 45ºC and 90ºC with respect to rolling direction.

3.4 Result and Discussion

Figures 5 depict how the percentage elongation, YS, and UTS vary with rolling direction for cryorolled and cold rolled samples. Table 3 provides a summary of the findings. Cryorolled sheets have revealed somewhat increased YS and UTS in both rolled and annealed regimes. It is evident that better strength and approximately equal ductility are produced by cryorolling, which is followed by quick annealing at a low temperature. Cryorolled sheets are more durable than cold rolled sheets as a result. The previously mentioned bimodal microstructure in cryorolled samples can be used to explain why cryorolled sheets have higher strength than cold rolled sheets while maintaining almost identical ductility.

Figure 5(a) shows the Comparison of UTS and YS for cold rolled and cryorolled sheet at 0º with respect to rolling direction. At 0º cold rolled annealed sheet have YS 117.507(MPa) and UTS 134.613(MPa) while cryo rolled annealed sheet have YS 134.648(MPa) and UTS 151.761(MPa). From this values of YS and UTS for both cold rolled and cryorolled annealed sheet we can say that there is a nearly 15% increase in YS and 13%increase in UTS for cryorolled annealed sheet as compared to cold rolled annealed sheet. Figure 5(b) shows the Comparison of UTS and YS for cold rolled and cryorolled sheet at 45º with respect to rolling direction. At 45º cold rolled annealed sheet have YS 123.472(MPa) and UTS 145.234(MPa) while cryo rolled annealed sheet have YS 128.857(MPa) and UTS 150.722(MPa). From this values of YS and UTS for both cold rolled and cryorolled annealed sheet we can say that there is a nearly 4% increase in YS and 4% increase in UTS for cryorolled annealed sheet as compared to cold rolled annealed sheet. Figure 5(c) shows the Comparison of UTS and YS for cold rolled and cryorolled sheet at 90º with respect to rolling direction. At 90º cold rolled annealed sheet have YS 120.114(MPa) and UTS 143.131(MPa) while cryo rolled annealed sheet have YS 154.161(MPa) and UTS 165.762(MPa). From this values of YS and UTS for both cold rolled and cryorolled annealed sheet we can say that there is a nearly 28% increase in YS and 16% increase in UTS for cryorolled annealed sheet as compared to cold rolled annealed sheet.

Figure 5(d) shows the Comparison of %Elongation for cold rolled and cryorolled sheet at 0ºC, 45ºC and 90ºC with respect to rolling direction. At 0º cold rolled annealed sheet have elongation 2.84% while cryo rolled annealed sheet have elongation 3.72%. From this values of elongation for both cold rolled and cryorolled annealed sheet we can say that there is a nearly 30% increase in elongation for cryorolled annealed sheet as compared to cold rolled annealed sheet. At 45º cold rolled annealed sheet have elongation 3.44% while cryo rolled annealed sheet have elongation 3.94%. From this values of elongation for both cold rolled and cryorolled annealed sheet we can say that there is a nearly 15% increase in elongation for cryorolled annealed sheet as compared to cold rolled annealed sheet. At 90º cold rolled annealed sheet have elongation 3.06% while cryo rolled annealed sheet have elongation 3.98%. From this values of elongation for both cold rolled and cryorolled annealed sheet we can say that there is a nearly 30% increase in elongation for cryorolled annealed sheet as compared to cold rolled annealed sheet.

Figures 6 show how the Variations in Load vs CHT of the cold and cryorolled samples at at 0°C, 45°C and 90°C with respect to rolling direction.

3.5 Conclusion

The impact of cold rolling and cryorolling on the mechanical properties of Al 8081 alloy was examined in the current experiment, and the following findings were reached.

- In comparison to cold rolled and annealed sheets, cryorolled AA 8011 alloy sheets with a thickness reduction of 3 to 1 mm and annealing at a low temperature of 200°C for 45 minutes give higher strength without losing ductility, leading to sheets with higher toughness and good damage tolerance ability.
- Improved hardness values were the result of strain hardening brought on by rolling reductions. When compared to CLR samples, CLR's AA8011alloy samples showed higher hardness values, probably because of the second-phase strengthening of the grain boundary regions.
- It is observed that there are significant improvements in yield strength and ultimate tensile strength with cryorolling due to high density of dislocations as compared to cold rolling.

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