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Effect of Cryorolling on Mechanical Properties of AI Alloy: A Review

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ABSTRACT

In the industry, demand for lightweight vehicle components is skyrocketing. The majority of these components are made using metal forming techniques to generate components that are lightweight, strong, and stiff. The majority of rolling procedures are used to increase the ductility and strength of the material. To change the rolling surface, an additional cross-rolling step is added during the deformation. This paper has reviewed the mechanical properties of al alloy sheet. The article focuses on the current situation, recent changes, and anticipated future orientations on the subjects. This article attempts to compare how well various rolling processes—such as room temperature rolling, cryogenic rolling perform on various materials in the literature. It has been discovered that cryorolling of aluminium alloys increases strength and hardness more than cold rolling because it effectively suppresses dynamic recovery, which raises the density of dislocations. Nonetheless, post-cryorolling techniques like warm rolling and low temperature annealing have been undertaken in an attempt to produce sheets with the best possible balance of ductility and strength because of the low ductility of the sheets in their as-cryorolled state.

Keywords: Aluminum alloys; cold rolling; cryorolling; hardness; tensile properties

INTRODUCTION

The rolling process is used to reduce the material's thickness. When rolling, one roller rotates in a clockwise motion while the other rotates anticlockwise direction as shown in Figure 1. The spacing between rollers ought to be closer than the thickness of the material that needs to be formed into a functioning piece. When metal is placed between two rollers, it is compressed and subjected to friction, which causes the metal to become thin and lengthened. Large bulk materials are shaped into more precise portions and long cross sections using the complex metal forming process of rolling.

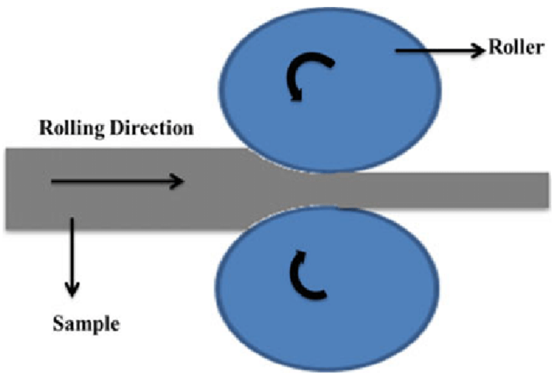

FIGURE 1. Schematic showing conventional rolling and cryogenic rolling
Source: Pant et al. 2022

Figure 2 shows the process flow Cold rolling is a method of manufacturing in which the procedure is carried out at recrystalline temperature. Cold rolling is mostly used to produce small, extremely strong pieces. Unlike hot rolling, cold rolling does not reduce thickness. To increase the ductility of steel, which is obtained from annealing, or cold rolling, rolling below recrystallization is used. High strength and superior surface finish are displayed by cold rolling methods. Cold rolled metal has been used to create bars, strips, rods, and sheet metals while having minimal buckling and torsional resistance.

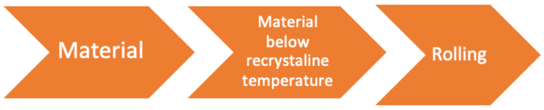

FIGURE 2. Flow diagram of cold rolling process.
Source: Pant et al. 2022

Cryorolling, also known as cryogenic rolling, is a type of severe plastic deformation process that involves the deformation of a material at cryogenic temperatures (Feyissa et al. 2018; Rao et al. 2013; Satish et al. 2017; Taye 2014). Figure3 shows a schematic diagram of conventional cold rolling and cryogenic rolling processes using a two high rolling mill. The use of cryogenic temperatures during the rolling process is known to improve the mechanical properties of many materials, including aluminium alloys. The cryorolling involves cooling the material to cryogenic temperatures, typically below -196ºC, and then performing the rolling process while maintaining this temperature. The cryogenic temperatures lead to a decrease in the material's grain size, which results in an increase in strength and hardness.

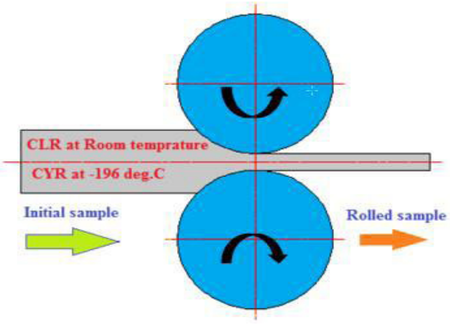

FIGURE 3. Schematic showing conventional rolling and cryogenic rolling
Source: Taye (2014)

Cryogenic rolling shown in Figure 4, also known as cryorolling, is one of the potential techniques to create nanostructured bulk materials from its bulk counterpart at cryogenic temperatures which is nearly -196ºC for liquid nitrogen. The majority of these methods require large plastic deformations (strains much larger than unity). In the case of cryorolling, the deformation in the strain hardened metals is preserved as a result of the suppression of the dynamic recovery. Figure 4 shows a Flow diagram of cryorolling process. In conventional cold rolling (CCR), the sheets are rolled at room temperature in number of passes to achieve the final thickness(Changela et al. 2020a).

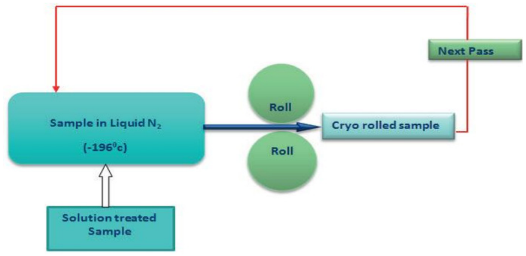

FIGURE 4. Flow diagram of cryorolling process
Source: Pant et al. (2022)

Low temperature annealing (to avoid significant loss of strength) of cryorolled aluminium alloy sheets could lead to sheets with a good combination of and formability. This is expected to further enhance the range of applications of aluminium alloys and other industries (Changela et al. 2020b).

Miller studied issue for the automobile industry is the rising desire for more fuel-efficient vehicles to reduce energy use and air pollution. Due to its distinctive qualities, such as its high strength stiffness to weight ratio, good formability, good corrosion resistance, and recycling potential, aluminium is the ideal material to replace heavier materials (such as steel or copper) in cars in order to satisfy the automotive industry's demand for weight reduction (Miller et al. 2000).

Hai Liang found interest in ultrafine-grained (UFG) materials has increased significantly. The employment of unique rolling processes to enhance the mechanical properties of UFG metal sheets is the main topic of this review. Asymmetric rolling, cryorolling, asymmetric cryorolling, cross-accumulative roll bonding, and skin-pass rolling are some of these methods. A mixture of processes, such as equal channel angular press and subsequent rolling, combined high-pressure torsion and rolling, combined accumulative roll bonding and subsequent asymmetric rolling, are also included in the approaches. We also go through the primary factors that the unique rolling procedures related to UFG materials' increased ductility (H. L. Yu et al. 2016).

Chandra Sekhar studied and found Al-Mg alloys are a unique class of materials through Al alloys with desirable properties such as high strength, good formability and superior corrosion resistance and are found to be appropriate for different applications in aerospace, automobile, marine and chemical industries. High mechanical strength is mainly derived from solid solution strengthening and dispersion hardening due to the existence of relatively high (> 3%) Mg content as an alloying element and it can also be strengthened by work hardening (Chandra Sekhar et al. 2014b).

Zhao studied Alloys having grain or subgrain structures that have been refined to a thickness of one micron or less typically have high strengths but insufficient tensile ductility. In the past, efforts to increase their ductility have typically resulted in the loss of strength. We have created a practical method for producing a 2024 Al alloy with high strength and excellent ductility. The method combines ageing to produce highly dispersed nano-precipitates, cryo-rolling to create a fine-structure with a high density of dislocations and submicrometer subgrains, and solution-treatment to partially dissolve T-phase particles. The accumulation of dislocations during cryo-rolling was shown to be greatly aided by the residual T-phase particles, and this in turn helped to promote the precipitation of nanosized S′ precipitates with an interparticle spacing of only 10–20 nm(Zhao et al. 2007).

Tharazi study uses the material qualities and process parameters learned from the literature as inputs to numerically simulate a multistage forming of an end-wall process in order to analyze the formability of sheet metal aluminum alloy AA6061. By contrasting its formability with the literature that Altair Hyperform replicated, the geometrical model was verified. Next, utilizing the Response Surface Methodology (RSM) in conjunction with the design of experiment technique, Analysis of Variance (ANOVA) was used to statistically analyze the impact of forming parameters on formability (Tharazi et al. 2024).

Enhancement of mechanical properties of aluminium alloys has been an area of interest to material scientists. For ductile materials, improvement of strength can be done by severe plastic deformation processes. These processes are typical metal forming processes where parent materials are subjected to extremely high strain in order to build Ultra Fine Grain Structure (UFGS) with superior strength at the cost of ductility of the material. Some of these are: Equal Channel Angular Pressing (ECAP), Accumulative roll-Bonding (ARB), High Pressure Torsion (HPT) and Cryogenic rolling (CYR).

Kim studied the high-pressure torsion's enormous shear strain causes the creation of dislocation cells and grain refining, which increases the alloy's strength and reduces its ductility. Deformation and frictional heat act as a catalyst for solute migration, brittle intermetallic complex dissolution, and matrix-generated nanoparticulate precipitation. By causing precipitation hardening and brittle phase dissolution at the same time, these solute migration activities help to improve both strength and ductility. As a result, the high-pressure torsion-processed aluminium 7075 alloy has a greater strength and ductility than in its initial form. This finding demonstrates how extreme plastic deformation processing of metallic alloys results in microstructural changes that significantly improve the mechanical properties of nanocrystalline materials (Kim et al. 2021).

Jagadeesh created lightweight AA2050 Al-Cu-Li alloy's microstructural development and mechanical characteristics have been reported. Multi-directional forging (MDF) at 170 °C and artificial ageing at 150ºC were the manufacturing steps used. After 12 rounds of MDF, systematic EBSD examination showed significant grain refinement, with grain size dropping from 74.3 12 to 22.1 2.8 m. Grain refinement has been achieved through the dynamic recrystallization of deformation bands into subgrains. According to TEM findings, peak aged MDF treated samples contain a significant amount of fine precipitates along with massive dislocation clusters and deformation bands. Due to generated lattice strain on MDF, XRD examination reveals fluctuation in peak intensities and the occurrence of peak shifts. After the 12th MDF pass, a sizable improvement in microhardness and strength was seen with a negligible trade-off in ductility. Furthermore, post-MDF aged samples showed improvements in strengths and microhardness. The combined impact of grain size reduction, strain hardening, and precipitate hardening on material strength is demonstrated by experimental results. The strength and ductility of AA2050 might be greatly improved by combining MDF and artificial ageing (Jagadeesh et al. 2023).

Rawat studied cryorolled LM6 Al alloy's EBSD and mechanical properties were examined. Cryorolling was used on solution-treated (ST) alloy to reduce thickness differences by up to 50%, 75%, and 90%. Utilizing EBSD and TEM microscopy techniques, as well as the tensile test and hardness, the influence of CR on the microstructure of the LM6 alloy was examined. When compared to ST LM6 Al alloy, the mechanical properties of the CR LM6 Al alloy are improved. The results showed that as the percentage of thickness reduction increased, the proportion of low angle grain boundaries and the average misorientation of the kernel also increased. In comparison to all sample conditions, the CR processed LM6 Al alloy exhibits improved mechanical characteristics, supporting the impact of grain refinement (Rawat et al. 2021).

M. Tiryakioğlu analyzed the link between Vickers hardness, yield stress, and tensile strength, data from two separate investigations using 7010 alloy plate and a rectilinear forging were combined. The two experiments' hardness-yield stress results overlapped, pointing to a potential basic link. When constraint factors derived from contact mechanics models were compared to the slope for the hardness-yield stress data, Shaw and DeSalvo's constraint factor emerged as the most compatible. The work hardening that occurs during Vickers testing was used to explain the y-intercept of the hardness-yield stress connection. A very reasonable fit was also provided to a third independent research by the equation that was discovered to suit the hardness-yield stress data for 7010 plate and forgings. Additionally, an empirical equation was created to express the link between tensile strength and hardness (Tiryakioğlu et al. 2015).

Xiong studied High-density dislocations, deformation twins, and deformation-induced martensites were always present in the deformation-induced martensite transition and the resulting deformation microstructure during the cryorolling process. Following the strain, the volume percentage of deformation twins and deformation-induced martensites rose noticeably, and the dislocation density in the deformation microstructure approached saturation condition. Original austenite totally changed into martensite at the 70% strain. The martensitic lamellae would be refined to a nanoscale by increasing the strain one more time to 90%. Additionally, the degree of deformation caused the strength and hardness of the cryorolled SS to increase noticeably, while the elongation was significantly reduced. The tensile fracture morphology changed as a result of the cryorolling from a normal ductile rupture to a combination of quasi-cleavage and ductile fracture (Xiong et al. 2017).

Changela tested mechanical qualities compared to coarse-grained materials; ultrafine-grained materials have a wide range of structural and functional uses. The present work has examined the effects of rolling AA 3003 alloy and pure Cu at ambient temperature and cryogenic temperatures on their mechanical characteristics and fracture behaviour. Rolling both materials to a thickness of 2 mm and 1 mm with real plastic strains of 0.40 and 1.09, respectively, results in the thicknesses. The tensile test, the hardness test, and the X-ray diffraction analysis are used to characterize the deformed samples. It has been found that cryorolled (CYR) samples have higher tensile strength and harderness than cold rolled (CR) samples. This is because rolling at such a low temperature (-196ºC) suppresses dynamic recovery, making it more difficult for dislocations to move, which increases dislocation density. When compared to materials with higher stacking fault energies (AA3003), materials with low stacking fault energies (Cu) have a higher tendency to become stronger and work-hardened without significantly losing ductility. According to a SEM visual depiction of fractography, CYR samples fail in a variety of ways as opposed to CR samples. Due to extreme strain hardening and grain refining, the dimple size rapidly decreases as the plastic strain increases (Changela et al. 2020c).

Changela studied the total elongation varies inconsistently in the case of AA 6061 alloy, the traditional trend of decreasing strength and increasing ductility within rising annealing temperature has been seen in the case of AA 5083 alloy (Changela et al. 2020a).

Rathod studied Magnesium alloys are among the lightest metals used in a variety of applications, such as the automotive and aerospace industries, and they have low density, good conductivity, good damping characteristics, and enough specific strength. However, their applications are limited due to the limited number of independent slip systems in hexagonal close packed (HCP) structures, which also limits their ductility and formability. Techniques like strain hardening and age hardening can enhance the properties of these alloys (Rathod et al. 2021).

Bobruk found the study mentioned investigated the formability of cryorolled aluminium alloy sheets in warm forming conditions. The researchers focused on two aluminium alloys, AA 5083 and AA 6061, which were cryorolled to different thickness reductions and then subjected to warm forming tests(Bobruk et al. 2021).

The results of the study showed that cryorolled AA 5083 and AA 6061 alloys exhibited improved formability in warm forming conditions compared to their non-cryorolled counterparts. The formability improvement was attributed to the formation of a fine and homogenous microstructure due to the cryorolling process.

The study also found that the formability improvement was more pronounced for the AA 6061 alloy compared to the AA 5083 alloy. This was attributed to the higher work hardening rate of the AA 6061 alloy, which allowed for better deformation and flow of the material during warm forming.

Furthermore, the study showed that the degree of thickness reduction during cryorolling had an effect on the formability of the aluminium alloys in warm forming. Higher thickness reductions resulted in improved formability due to the formation of a finer microstructure, while lower thickness reductions had a limited effect on formability.

Overall, the study concluded that cryorolling can significantly improve the formability of aluminium alloys in warm forming conditions. This has potential implications for the use of cryorolled aluminium alloys in industries such as automotive and aerospace, where warm forming is commonly used for the production of complex components.

Nikhil Kumar studied it was examined how the 6082 Al alloy responded to cryorolling (CR) and annealing (AN) treatments in terms of recovery, recrystallization, grain growth, mechanical resistance, and corrosion resistance. After performing CR to create an ultrafine grained structure, AN treatment was applied to determine how it affected recovery, recrystallization, and grain growth. While grain growth begins at 300ºC because of insoluble dispersions (AlMn & AlMnSi) and Mg2Si precipitates in the alloy, as shown by results from Differential scanning calorimetry (DSC), Electron back scattered diffraction (EBSD), hardness, and Transmission electron microscopy (TEM) tests. The recovery and recrystallization occur between 110 and 250ºC and 250-300ºC, respectively. Increased hardness of 120 VHN and ultimate tensile strength of 353 MPa were demonstrated by the CR 6082 Al alloy. Maximum hardness, ultimate tensile strength (UTS), and ductility of CR 6082 Al alloy at 150ºC were measured at 127 VHN, 362.5 MPa, and 11%, respectively. The high dislocation density and increased grain boundary area caused by the corrosion resistance of the 6082 Al alloy allowed for the production of a dense oxide coating on the surface, increasing corrosion resistance. When compared to a deformed Al alloy, CR samples annealed at 350ºC have outstanding corrosion resistance (Kumar et al. 2015).

Sekhar studied The study you mentioned investigated the effect of annealing on the microstructure and mechanical properties of Al 6061 alloy processed by cryorolling. The researchers cryorolled the Al 6061 alloy to different thickness reductions and then annealed the samples at different temperatures and times to study the effect on the microstructure and mechanical properties(Sekhar et al. 2014).

The results of the study showed that cryorolled Al 6061 alloy had a fine and homogenous microstructure with a high density of dislocations. Annealing the cryorolled samples led to the formation of equiaxed grains and a reduction in the density of dislocations, resulting in an increase in ductility and toughness.

The researchers found that the optimum annealing temperature for the cryorolled Al 6061 alloy was 250ºC, which resulted in the highest improvement in ductility and toughness. The increase in ductility and toughness was attributed to the recrystallization of the material during annealing, which led to the formation of a fine and equiaxed grain structure.

However, the study also showed that excessive annealing at higher temperatures or for longer times led to the formation of coarse grains and a reduction in mechanical properties. This was attributed to the coarsening of the microstructure during annealing, which led to a decrease in strength and hardness.

Overall, the study concluded that annealing can be used to further improve the mechanical properties of cryorolled Al 6061 alloy. However, the annealing conditions must be carefully controlled to ensure the formation of a fine and homogenous microstructure, while avoiding excessive coarsening of the grains.

Chandra Sekhar characterize the microstructure, mechanical properties, and formability of cryorolled AA5083 alloy sheets. The researchers cryorolled the AA5083 alloy to different thickness reductions and investigated the resulting microstructure, mechanical properties, and formability (Chandra Sekhar et al. 2014b).

The results of the study showed that cryorolled AA5083 alloy sheets had a fine and homogenous microstructure, which led to an increase in strength and hardness compared to the non-cryorolled alloy. The increase in strength and hardness was attributed to the formation of a high density of dislocations during cryorolling, which impeded the motion of dislocations and increased the strength of the material.

The researchers also found that the formability of cryorolled AA5083 alloy sheets was significantly improved compared to non-cryorolled sheets. The improved formability was attributed to the fine and homogenous microstructure of the cryorolled material, which allowed for better deformation and flow during forming.

Furthermore, the study showed that the degree of thickness reduction during cryorolling had a significant effect on the mechanical properties and formability of the AA5083 alloy. Higher thickness reductions resulted in higher strength and hardness, but also led to a decrease in formability due to the increased deformation resistance of the material.

Overall, the study concluded that cryorolling is an effective method for improving the mechanical properties and formability of AA5083 alloy sheets. The fine and homogenous microstructure resulting from cryorolling led to an increase in strength and hardness, while also improving the formability of the material.

Feyissa characterize the mechanical properties and formability of cryorolled aluminum alloy sheets. The researchers cryorolled the aluminum alloy to different thickness reductions and investigated the resulting mechanical properties and formability(Taye 2014).

The results of the study showed that cryorolled aluminum alloy sheets had an increase in strength and hardness compared to the non-cryorolled alloy. The increase in strength and hardness was attributed to the formation of a high density of dislocations during cryorolling, which impeded the motion of dislocations and increased the strength of the material.

Furthermore, the study showed that the formability of cryorolled aluminum alloy sheets was significantly improved compared to non-cryorolled sheets. The improved formability was attributed to the fine and homogenous microstructure of the cryorolled material, which allowed for better deformation and flow during forming.

The researchers also found that the degree of thickness reduction during cryorolling had a significant effect on the mechanical properties and formability of the aluminum alloy. Higher thickness reductions resulted in higher strength and hardness, but also led to a decrease in formability due to the increased deformation resistance of the material.

The study also investigated the effect of annealing on the mechanical properties and formability of cryorolled aluminum alloy sheets. The results showed that annealing could further improve the mechanical properties and formability of the cryorolled material. The optimum annealing temperature for the cryorolled aluminum alloy was found to be 250ºC, which resulted in the highest improvement in ductility and toughness.

Overall, the study concluded that cryorolling is an effective method for improving the mechanical properties and formability of aluminum alloy sheets. The fine and homogenous microstructure resulting from cryorolling led to an increase in strength and hardness, while also improving the formability of the material. Annealing can also be used to further improve the mechanical properties and formability of the cryorolled material.

Singh investigate the microstructural changes that occur in Al 5083 alloy when it is subjected to cryorolling. The researchers used various characterization techniques to analyze the microstructure of the alloy after different degrees of thickness reduction through cryorolling(Singh et al. 2012).

The results of the study showed that cryorolling resulted in a significant increase in the density of dislocations within the material, leading to an increase in strength and hardness. The researchers observed that as the degree of thickness reduction increased, the dislocation density also increased.

Furthermore, the study showed that cryorolling also led to a refinement of the microstructure of the material, with a reduction in the size of grains and sub-grains. This refinement was attributed to the formation of deformation bands during cryorolling, which led to the formation of new grains with smaller sizes.

The researchers also observed that the cryorolled material exhibited anisotropic properties, with the direction of rolling having a significant effect on the mechanical properties of the material. The researchers suggested that this anisotropy may be due to the alignment of dislocations and grains along the rolling direction.

Overall, the study concluded that cryorolling is an effective method for refining the microstructure and improving the mechanical properties of Al 5083 alloy. The increased dislocation density and grain refinement resulting from cryorolling led to an increase in strength and hardness. The study also highlighted the importance of considering the anisotropic properties of cryorolled materials in their applications.

Liu investigate the microstructural evolution during cryo-severe plastic deformation and post-deformation annealing of aluminum and its alloys. The researchers used various characterization techniques to analyze the microstructure of different aluminum alloys after cryo-severe plastic deformation and post-deformation annealing(Liu et al. 2023).

The results of the study showed that cryo-severe plastic deformation led to a significant refinement of the microstructure of the alloys, with a reduction in the size of grains and sub-grains. The researchers observed that as the degree of deformation increased, the grain refinement became more pronounced.

Furthermore, the study showed that post-deformation annealing led to a recovery and recrystallization of the microstructure, resulting in an increase in the size of grains and a decrease in the density of dislocations. The extent of recovery and recrystallization depended on the annealing temperature and time.

The researchers also observed that the cryo-severe plastic deformation led to the formation of deformation bands, which were regions of high deformation and high dislocation density. These deformation bands were responsible for the refinement of the microstructure.

Overall, the study concluded that cryo-severe plastic deformation is an effective method for refining the microstructure of aluminum alloys, leading to an increase in strength and hardness. The study also highlighted the importance of post-deformation annealing in controlling the microstructure and properties of the alloys.

Guoai He studied The annealed 2195 Al-Cu-Li alloy plates were then exposed to ageing treatment at 175ºC for varying lengths of time, followed by solid solution at 540ºC for 2 hours. While the yield strength of the cryogenic rolling sample was higher anomalously, both the tensile strength and ductility of the heat-treated specimen increased in comparison to the as-rolled sample (He et al. 2021).

Vineet Kumar studied grain refinement, grain fragmentation, high angle boundaries, and the creation of ultrafine grains, the microstructure of the cryorolled (CR) and room temperature rolled (RTR) 6082 Al alloy with varied thickness reductions, i.e. 40%, 70%, and 90%, is characterized by EBSD and TEM. As a result of improved tensile strength, CR exhibits better mechanical qualities than RTR alloy(Kumar and Kumar 2017).

Singh studied “Microstructures and Impact Toughness Behavior of Al 5083 Alloy Processed by Cryorolling and Afterwards Annealing” was published in the International Journal of Minerals, Metallurgy, and Materials in 2013. The authors of the paper are D. Singh, P. NageswaraRao, and R. Jayaganthan(Singh et al. 2013).

The article investigates the impact toughness behavior of aluminum 5083 alloy after being processed by cryorolling and annealing. The microstructures of the alloy were also analyzed using scanning electron microscopy and transmission electron microscopy.

The results showed that cryorolling followed by annealing led to an increase in the impact toughness of the alloy. The microstructures of the alloy after the process showed the presence of fine grains and a reduction in the grain size of the alloy.

Overall, the study highlights the potential of cryorolling and annealing as a means of improving the impact toughness behavior of aluminum 5083 alloy, which could have implications for the use of the alloy in various industrial applications.

Satish studied the effects of cryorolling (cold rolling at cryogenic temperatures) and warm forming (forming at elevated temperatures) on the mechanical properties of AA6061 aluminum alloy sheets. The authors conducted experiments to evaluate the microstructure and mechanical properties of the sheets after cryorolling and warm forming, and compared them to the properties of sheets processed by conventional rolling and forming techniques (Satish et al. 2017).

The results of the study showed that cryorolling produced a finer and more homogeneous microstructure in the aluminum sheets, resulting in improved strength and hardness compared to conventional rolling. However, the ductility and toughness of the cryorolled sheets were lower than those of conventionally rolled sheets. On the other hand, warm forming produced improved ductility and toughness compared to conventional forming, while maintaining similar strength and hardness.

The authors also investigated the effects of combining cryorolling and warm forming, and found that the combination resulted in a synergistic improvement in the mechanical properties of the aluminum sheets. The cryorolled sheets exhibited higher strength and hardness, while the warm formed sheets showed improved ductility and toughness.

Overall, the article provides insights into the potential benefits of cryorolling and warm forming for enhancing the mechanical properties of aluminum alloys, and suggests that a combination of these techniques may lead to further improvements in the properties of these materials.

Ridzuan studied Using liquid nitrogen (LN2) and coated carbide cutting tools in a high-speed turning process, this study examines the impact of cutting parameters on the machinability of M303 in a cryogenic setting. Cutting pressures, surface finish, and tool life are among the crucial machinability aspects that are examined in this study, which focuses on high cutting speeds. A Taguchi L4 orthogonal array is used in the experimental design to systematically investigate high cutting speeds (260–340 m/min), depth of cut (0.2–0.6 mm), and feed rates (0.1–0.2 mm/rev).Notably, the study shows that the longest tool life of 48.57 minutes was attained at a low cutting speed of 260 m/min, along with low feed rates and depth of cut. Ra of 0.9 μm and cutting force of 100 N, respectively, indicate modest cutting forces and an excellent surface quality in this setting(Ridzuan et al. 2024).

Jayaganthan studied on the effects of cryorolling (cold rolling at cryogenic temperatures) on the precipitation kinetics of Al 7075 alloy. The authors conducted experiments to investigate the microstructure and precipitation behavior of the alloy after cryorolling with different strain levels, and compared them to the properties of the alloy processed by conventional rolling techniques (Jayaganthan and Panigrahi, 2008).

The results of the study showed that cryorolling produced a significant refinement of the microstructure in the Al 7075 alloy, with a higher density of dislocations and a greater number of fine precipitates. The authors also found that the precipitation kinetics of the alloy was affected by the cryorolling strain, with a higher strain resulting in a faster rate of precipitation.

Furthermore, the article discusses the mechanisms responsible for the enhanced precipitation kinetics in the cryorolled alloy, including the increased number of nucleation sites and the greater diffusion rate of solute atoms. The authors also suggest that cryorolling can be a useful technique for controlling the precipitation behavior of Al 7075 alloy, leading to improved mechanical properties and better performance in structural applications.

Overall, the article provides insights into the effects of cryorolling on the microstructure and precipitation kinetics of Al 7075 alloy, and suggests that this technique can be a promising approach for improving the performance of this important material. The effect of cryorolling was studied on AA5083 and The results showed that the hardness values increased as the rolling reduction was increased.(Krishna et al. 2015) Here in this article we studied the effect of cryorolling on different parameters of mechanical properties like hardness, tensile properties for cold rolled condition as well as cryorolled conditions.

Hailiang Yu conducted experiment on ultrafine-grained (UFG) Al sheets that underwent accumulative roll bonding (ARB) and subsequent cryorolling to examine the microstructure evolution and mechanical characteristics. The dynamic softening of UFG Al sheets exposed to ARB at room temperature can be prevented by cryorolling. As the number of ARB passes rises, the grains become marginally more refined after the third ARB pass. Cryorolling, however, much further refines the grains. The 460 nm grain size attained after the third ARB run is reduced to 290 nm after two passes through the cryoroller, for a total reduction ratio of 80%. Due to a change in the proportion of high-angle boundaries and elongated grains, sheets exposed to ARB + cryorolling exhibit enhanced mechanical characteristics in comparison to sheets treated to ARB processing alone(H. Yu et al. 2016).

Panigrahi studied tensile tests, SEM/electron back scattered diffraction (EBSD), transmission electron microscope (TEM), DSC, and X-ray diffraction (XRD), aluminium alloy (6063) was severely rolled up to 92% thickness reduction at liquid nitrogen temperature and room temperature in order to study the effect of rolling temperature on its mechanical properties and microstructural characteristics in comparison to room temperature rolled (RTR) material with the same deformation strain. In comparison to the rolled alloy at normal temperature (232 MPa), the cryorolled 6063 Al alloy had a higher strength (257 MPa). The accumulation of more dislocations in the cryorolled alloy than in the rolled material at ambient temperature is what gives it its increased strength. Measurements were made of the tensile characteristics of both the cryorolled alloy and the alloy that underwent various annealing processes. The cryorolled alloy exhibits an ultrafine-grained (UFG) microstructure with increased tensile strength and ductility after being annealed at 300ºC for 5 min (S.K. Panigrahi and Jayaganthan, 2008).

Krishna studied distinct temperatures, namely 28ºC (301 K) and 196ºC (77 K), aluminium lithium alloy was rolled. In each case, the alloy's thickness was cut by 75% from its starting point of 6 mm. All samples underwent X-ray diffraction examination to assess the grain size and dislocation density. According to micrographs created using transmission electron microscopy, the cryorolled sample had finer grains and a higher dislocation density. The rolled samples had a bimodal grain distribution, with the cryorolled sample showing a greater proportion of ultrafine grains, according to electron backscattered diffraction pictures. On rolled samples, tensile and hardness tests were run. When compared to rolled samples at normal temperature, cryorolled samples had improved characteristics. The void coalescence behaviour of broken samples was examined using scanning electron microscope pictures. In all cases, the findings of the analysis of the various void coalescence parameters such as void size, void area, length to width ratio of void, and ligament thickness—were linked with microstructure, mechanical characteristics, crystallite size, and dislocation density (Krishna et al. 2017).

Taylor studied the microstructure; sheets of precipitate-hardenable 2024 aluminium were rolled at liquid nitrogen temperature. Differing aging/heat treating techniques has been used, producing materials with noticeably differing mechanical characteristics. The mechanical characteristics of the cryo-rolled material were assessed as a function of the heat treatment holding time at 150ºC. Precipitates that generated during the ageing step, rolling process, or subsequent heat treatment were found to have a significant impact on the final characteristics. A limiting dome height test (also known as the Erichsen cupping test) has been used to examine the formability of the material that has been cryo-rolled and heat treated (Taylor et al. 2013).

EFFECT OF CRYOROLLING ON HARDNESS

Recently, a lot of research activities are focused to improve the strength and ductility of severely deformed age hardenable Al alloys. The hardness of CR and RTR samples have been studied for al alloys with different parameters. The hardness data of the Al 7075 alloy samples (ST, CR and RTR) measured after ageing at 140ºC vs. ageing time up to 70h.There is a significant increase in hardness upto 35h (71% increase) and then it decreases in case of ST samples On the other hand, the CR and RTR samples exhibit an opposite trend; hardness decreases with time. It may be because of the recovery effect which might have occurred during a high temperature ageing of the CR and RTR samples with time. The effect of ageing treatment at 120ºC upto 70h on the ST, CR and RTR samples. The hardness of the CR and ST samples is increased from 190 to 199 Hv and 107 to 189 Hv, respectively. However, the hardness decreases with ageing time for RTR samples (Panigrahi and Jayaganthan, 2011a). In some cases of AA7075 the hardness values of the solution treated as a function of true rolling strain. The true strain corresponds to different percentage of thickness reduction in the samples. The hardness of the cryorolled materials has increased from 80 to 150 Hv (nearly 88% increase) after 35 percent thickness reduction (e = 0.4). Subsequent thickness reductions of the samples increased its hardness further and after 90 percent thickness reduction (e=2.4), it has increased about 130 %. It is observed that the hardness of cryorolled alloys is higher than that of RT rolled materials at different strains. (Sushanta Kumar Panigrahi and Jayaganthan, 2008). For AA5083 the average Vickers micro hardness value of cryorolled is found to be 153HV which is much higher than hardness of cryorolled sheets. However, ductility of cryorolled sheets in the as-rolled condition is very poor when compared to conventionally rolled (CR) and annealed sheets which makes improvement in ductility when cryorolling followed by annealing. (Indian Institute of Technology Delhi, New Delhi, India 110016 et al. 2018).

Wang studied the performance and microstructure characterization of cryogenic rolling (CR) and room-temperature rolling (RTR) Al-Mg-Si alloys were thoroughly examined in this study. The outcome shown that the RTR alloys' early ageing stage hardness rose while the CR alloys' early ageing stage hardness decreased. The CR alloys showed retrogression characteristics in the early stages of ageing. Even though the CR alloys underwent the identical solid solution treatment, some substructures were still present, and their level of recrystallization was noticeably lower than that of the RTR alloys. The strength and density of the precipitates in the CR75 alloy were higher after ageing for 50 hours than in the other alloys, indicating that the substructures were advantageous to precipitation and precipitate growth. To show the precipitation contribution at various ageing phases, a model of precipitation strength was used. The findings demonstrated that the highest precipitation strengthening was achieved by the CR 75 alloy(Wang et al. 2023).

Zhang found that Cryorolling (CR) may effectively avoid high-strength aluminium alloy rolling cracks at room temperature. Solution-treated bulk Al 7085 alloy samples were exposed to CR and room temperature rolling (RTR) in this study. The RTR sample was fractured at 70% deformation, but the CR sample showed no cracks even at 90% distortion. As a result, the microstructure and mechanical characteristics of the CR samples were studied before and after ageing treatment. The yield strength (YS) and ultimate tensile strength (UTS) of solution-treated bulk Al 7085 alloy samples were enhanced by 74% and 31%, respectively, following cryorolling(Zhang et al. 2022).

Hao Gu performed work on AA5083 sheets were cryorolled at 83, 173, and 298 K to investigate the influence of cryorolling on the high-temperature mechanical characteristics of aluminium alloys, and the rolled sheets were subsequently submitted to high-temperature tensile testing at 748 K. At a strain rate of 1 103 s1, the elongation to failure of the 83 K cryorolled samples reached 150%, which was greater than that of the 173 K cryorolled samples (92%), and the 298 K rolled samples (80%). The strain rate sensitivity coefficient of the 83 K rolled samples was 0.36 under these conditions, meeting the requirement of super plasticity. The finer grains, smaller second phase, and subgrains easing higher stress concentration were attributable to the improved flexibility of the 83 K cryorolled samples. Grain-boundary sliding and dislocation slip were the primary deformation processes during high-temperature tensile deformation. The grain size of the 83 K cryorolled sample was lower than that of the 298 K rolled sample, making it appropriate for the grain-boundary sliding mechanism. Furthermore, the homogeneous distribution of high-density dislocations prevented dislocation slip but lowered stress concentration and cavity nucleation and expansion during high-temperature deformation(Gu et al. 2022).

Hanqing Xiong carried out Cryorolling (CR), room temperature rolling (RTR), and subsequent ageing treatment on mechanical and corrosion characteristics of 7050 aluminium alloy (AA7050) were examined in this work. In CR and RTR AA7050 alloys, the ultrafine-grained structure and high-density dislocations are generated after extreme rolling deformation. When compared to RTR AA7050, CR AA7050 has a greater volume proportion of UFGs and dislocation density. The precipitation technique for CR and RTR AA7050 alloys is nucleation, growth, and coarsening. The DSC test results suggest that CR AA7050 has a greater reaction to ageing therapy as well as an age-hardening impact. The micro-hardness (253 HV), yield strength (650 MPa), and ultimate tensile strength (685 MPa) of CR AA7050 are greater, but the elongation (2.2%) is lower than that of RTR AA7050 (245 HV, 573 MPa, 613 MPa, 3.5%). The ageing procedure can increase the elongation of rolled samples while gradually decreasing the other mechanical characteristics as the ageing duration increases. CR and RTR AA7050 sheets have low corrosion resistance, although CR improves the corrosion resistance of older samples(Xiong et al. 2022).

Yuze Wu tested CoCrFeNiMn high-entropy alloy (HEA) sheets were cryorolled at 223 K, cold rolled, and then annealed. Mechanical and microstructure characteristics of rolled and annealed HEA sheets were investigated. When compared to cold-rolled samples, cryorolled samples had higher strength and ductility. The yield stress of HEA grew to 1259 MPa after cryorolling from 161 MPa in its as-cast form, while it is 1082 MPa for cold-rolled HEA. Cryorolled samples preserved better strength and ductility after annealing than cold-rolled materials. Secondary twins, nano twins with greater proportions and smaller spacing, contributed to cryorolled HEA's improved strength and ductility. Continuous recrystallization occurred in cryorolled materials by subgrain migration during subsequent annealing, whereas cold-rolled samples had discontinuous recrystallization via grain boundary arched nucleation. Finally, we concentrated on the process of microstructure development(Wu et al. 2022) during annealing.

Yogesha K K looked into how the mechanical behaviour of AA 5052 is affected by cryo groove rolling followed by warm rolling (CGW). The cryo groove rolling (CGR) and warm rolling to a real strain of 2.3 were applied to the solution treated (ST) Al alloys at various temperatures. In comparison to ST alloy, the CGR samples that were rolled at 175ºC display increased strength (328 MPa), hardness (131 Hv), and ductility (4.1%). It was brought on by the development of a duplex microstructure made up of both elongated and equiaxed subgrains. The improvement in tensile strength of CGW samples is also caused by the production of tiny precipitates and broken or deformed impurity phase particles. Additionally, the deformed (CGW) material was given a post-annealing treatment between 180 and 300°C for one hour to examine its impact on the alloy's mechanical behaviour. The samples that have been post-deformation annealed and contain both coarser and finer grains have increased ductility (24.7%) and fracture toughness (115.8 kJ/m^2). Through optical microscopy, X-ray diffraction, SEM fractography, and TEM, the microstructural characterization of the deformed material was carried out, and it was connected with the tensile and fracture parameters of the alloy(K K et al. 2016).

Shisen Yang investigates cryorolling and room-temperature rolling was used to prepare AA7075 sheets, followed by ageing. Hardness measurements, tensile testing, X-ray diffraction, scanning electron microscopy, and transmission electron microscopy were used to explore the microstructure development and mechanical characteristics of AA7075 sheets. The results demonstrate that with an 80% rolling reduction ratio, the room-temperature rolled samples had large edge cracks, but the cryorolled samples were in good form and had no cracks. Less edge fractures were caused by enhanced ductility of materials in cryogenic settings, less precipitation, and the lack of shear bands in sheets during cryorolling. When compared to solution-treated materials, cryorolled samples enhanced their yield strength and ultimate tensile strength by 155% and 44%, respectively, while elongation fell as a loss, which is definitely better than room-temperature rolled samples. The rolled samples' strength and ductility were concurrently enhanced with the following ageing process, with the yield strength of cryorolled + peak-aged samples increasing by 44 MPa and elongation increasing by 68% as compared to cryorolled samples. The strength of cryorolled + peak-aged samples was greater than room-temperature rolled + peak-aged samples, and the elongation to failure and uniform elongation were raised by 58% and 72%, respectively. After ageing, several nanosized GP zones and' phases precipitated, and precipitation strengthening is the primary contributor to the samples' strength improvement. The combined impact of dislocation annihilation, uniform deformation, and tiny precipitates in cryorolled + peak-aged materials results in increased ductility(Yang et al. 2023).

Tanya Verma performed the influence of cryo-deformation and post-deformation annealing on the tensile, anisotropic, and fracture behaviour of AA2099 was examined in this study. The creation of ultrafine-grained (UFG) microstructure is initiated by cryorolling (CR) the solution-treated (ST) alloy at a real strain value of 2.3. Cryorolled samples are subsequently annealed at temperatures of 150°C (CR + 150°C) and 200°C (CR + 200°C). There was a significant increase in yield strength (342 MPa), ultimate tensile strength (472 MPa), hardness (138 HV), and fracture toughness parameters (KQ (31.8 MPam). Kee (31 MPam), and J integral (57.67 kJ/m2) are measured. While anisotropy rises in the rolling direction, ductility decreases significantly in the CR sample condition as compared to coarse grains in the ST condition. Significant improvements in tensile, anisotropic, and fracture behaviour of UFG AA2099 were reported after annealing at 150°C and 200°C. Tensile strength, anisotropy, and fracture toughness have been demonstrated to increase significantly until temperature hits 150°C (506 MPa), beyond which these parameters have been shown to decline significantly(Verma et al. 2023).

Jha et al. (Engineering Department, Ibra College of Technology Ibra, Sultanate of Oman et al. 2015) studied about the growing industrial, automotive, and construction industries' enormous demand for copper and brass, these metals must have their mechanical characteristics improved by the addition of suitable alloying elements. The goal of this research is to examine how different alloy additions to copper and brass affect those materials' tensile strength, hardness, and microstructure. Tensile strength, impact strength, and Rockwell hardness have been used to describe the mechanical properties of two copper alloys and two brass alloys. Brass and copper alloy specimens that had been annealed were examined for their mechanical characteristics and microstructure. According to the findings, both examples' tensile strengths rise as alloy addition is increased. After tensile testing, the fracture surface's microstructure was analyzed under an inverted microscope. According to the experimental findings, E-Cu exhibits greater ductility than pure copper and C38500 brass alloy exhibits greater ductility, yield strength, and tensile strength than brass type 1 after being annealed at two temperatures on specimens of two copper alloys and two brass alloys.

Magalhães studied Cryogenic rolling was used to produce three different materials, AA1050 Al alloy, pure copper, and Cu-15Zn alloy, each of which had a different stacking fault energy. The goal was to replace dynamic recovery with a greater buildup of faults. Vickers hardness testing, optical metallography, and tensile tests were used to describe the treated samples. Cu and Cu-15Zn underwent simultaneous increases in strength and ductility during cryogenic deformation, which was explained by twin-mediated deformation(Magalhães et al. 2014).

Moradpour studied classical constrained-groove pressing (CGP) process was used in this study to apply severe plastic deformation (SPD) to an Al-Mg alloy (AA5052series) in the annealed condition with sheet form geometry, resulting in an equivalent plastic strain of 2.32 imposed into the sheets. Dynamic strain ageing behaviour of these processed Al-Mg alloys up to different passes was evaluated in relation to the microstructural features (cellular structure formation and precipitates morphology) by elaborating the tensile property along rolling (RD) and transverse (TD) directions of sheets in terms of anisotropy. Additionally, the impacts of the SPD processing were contrasted with the effects of the thermo-mechanical treatment in the H34-temperature condition on the properties of the Al-Mg alloy. After implementing two CGP passes, the results demonstrated refinement of the initial annealed alloy's coarse grain structure (50 m) into the ultra-fine range (400–500 nm), significantly enhancing the homogeneity of the mechanical property. With a significant decline in elongation (>90%), hardness, yield, and tensile strengths were continually enhanced up to 55%, 110%, and 20%, respectively. To build a microstructure-mechanical strength link, it is noteworthy that the strengthening mechanisms were elaborated via dislocation-based models(Moradpour et al. 2019).

Feyissa explore this research and shows that the formability of high strength cryorolled Al alloy sheets can be improved by hydroforming because it results in less thinning and more uniform strain distribution. As a result, this process route (cryorolling followed by hydroforming) is a potential method to produce complex parts from lightweight high strength Al alloy sheets because of the enhanced formability(Feyissa and Kumar, 2019).

Cui studied the impact of various annealing treatment procedures on the mechanical properties and microstructures of cryogenic rolled AA 8011 was examined in order to increase the application field and improve the mechanical properties of roll cast 8011 aluminium alloy (AA 8011) by reinforcing the grain. Six cryogenic passes were made on the roll-cast AA 8011 before it was annealed. The annealing process was carried out first at 100–300ºC for 1 hour, and then at 220ºC for 10–80 minutes. OM was used to examine the microstructures of AA 8011 in the roll-cast and cryogenic rolled states. The Image-pro-plus 5.0 programmed calculated the grain size. TEM and energy dispersive spectroscopy studies were used to study the microstructures of AA 8011 during annealing states. The outcomes demonstrate that following annealing; the second phase Al 8 Fe 2 Si manifests itself in the cryogenic rolled AA 8011. The dislocation has a pinning role when it moves within the grain, which is advantageous for grain refining. Optimal thermal stability was achieved during the 40-minute optical annealing process at 220ºC. The optimal grain size, hardness, and tensile strength are 1 m, 65 HV, and 202 MPa, respectively. It is almost 1.5 times bigger than the AA 8011 roll cast(Cui et al. 2019).

Chen studied comparison to peak-aging, the pre-aging treatment allowed the alloy to have a stronger cryorolling work hardening effect and a higher potential for precipitation. This was because pre-aging increased the dislocations that accumulated during specimen cryorolling while promoting secondary precipitation during subsequent ageing following specimen cryorolling(Chen et al. 2016).

Bobruk investigations show that the UFG 6060 alloy of the Al-Mg-Si system can be produced into a structural state with an average grain size of 130 8 nm and a shape form of 1.2 when subjected to severe plastic deformation processing at RT(Bobruk et al. 2021).

Sahoo studied the microstructural development of Ti-6Al-4V alloy sheets exposed to asymmetrical cryorolling, warm rolling, and hot rolling up to 50 and 75% thickness reductions was highlighted in this work. Due to ultrafine grain refinement, cryorolling assists in creating a unique combination of high strength and ductility following adequate heat treatment techniques. Microstructural behaviours show that the average grain size is the smallest for Ti-6Al-4V sheet during cryorolling conditions, when the average grain sizes recorded are 497, 369, and 216 nm after 50% thickness reduction, and 301, 253, and 106 nm after 75% thickness reduction due to asymmetrical hot rolling, warm rolling, and cryorolling, respectively. The materials treated to 75% thickness reduction by cryorolling also exhibit the maximum hardness (VHN395). Furthermore, phase analysis of the dual-phase Ti-(+) alloy was completed, demonstrating the implications of the existence of the -Ti phase and the balance alongside its -Ti counterpart that control its mechanical characteristics. In combination with these research, a basic FEM simulation of a standard rolling process using ABAQUS 2019 software has been demonstrated for better understanding. Sushanta Kumar Panigrahi et al (Panigrahi and Jayaganthan, 2011b) explore the increased dislocation density and grain size effect are responsible for the cryorolled AA7075 samples' improved strength and hardness. The grain refining and strain hardening mechanisms functioning in the severely deformed samples are confirmed by the reduction in dimple size of cryorolled Al 7075 alloy upon failure(Sahoo et al. 2023).

Table 1 shows the effect of cryorolling on hardness with different parameters:

TABLE 1. Effect of Cryorolling on Hardness of alloy

Sr.No	Material	Processing Parameter	Hardness (VHN)	Ref
1	AA5083 alloy	As rolled (80% reduction)	148	(Feyissa et al. 2014)
		Annealing Temp. 150°C	139	
		Annealing Temp. 200°C	127	
		Annealing Temp. 250°C	116	
		Annealing Temp.300°C	94	
2	AA5083 alloy	Solutionised	95 ± 4	(Krishna et al. 2015)
		RTR50	131 ± 4	
		LNR50	131 ± 7	
		RTR75	147 ± 3	
		LNR75	147 ± 4	
3	Al 7075 alloy	Starting bulk alloy	81	(Prosenjit Das et al. 2011)
		40% room temperature rolled	137	
		40% cryorolled	155	
		70% room temperature rolled	160	
		70% cryorolled	137	
4	AA5083	Coldrolled+Annealed	85 HV	(Indian Institute of Technology Delhi, New Delhi, India 110016 et al. 2018)
		Cryorolled	153 HV	
5	Copper	Cold Rolled (20%)	75.33	(Paghadal and Changela, n.d.)
		Cryorolled (20%)	82.33	
		Cold Rolled (40%)	85	
		Cryorolled (40%)	90.8	

EFFECT OF CRYOROLLING ON TENSILE PROPERTIES

Navya carried out the production of ultrafine grained (UFG) Al alloys with improved tensile and fracture strength compared to bulk alloys has piqued the interest of the aerospace and automotive industries due to the possibility of realising very high specific strength while reducing structural component weight. Cryorolling and multiaxial forging were used to create ultrafine grained AA 2014 alloy, and its tensile behaviour was examined in this study. To understand the strain hardening behaviour of UFG Al alloys with regard to the bulk alloy, FEM modelling of deformation properties of UFG Al alloys was done utilising experimental tensile data for various cryogenic temperatures. Because to the enhanced dislocation density and grain size impact, the tensile strength of UFG Al alloy has improved greatly when compared to bulk Al alloy. The FEA of tensile properties of UFG Al alloys at different processing temperatures was performed using ABAQUS software, and it was demonstrated that the simulated strain hardening behaviour of the Al alloy matched that of experimental data(Navya et al. 2022).

Abbas investigated the effects of annealing on the formability, mechanical properties, and chemical composition of 7075 alloy. During the bending test, the formability was attained. Tests for microstructure, corrosion, tensile strength, and hardness are examples of mechanical and chemical qualities. The test specimens were prepared for each test and then heated to 200 and 300ºC in an electrical furnace for two hours as part of the annealing heat treatment. The samples were then permitted to cool in the furnace to room temperature. The findings show a 50% reduction in both tensile strength and hardness. In comparison to base metal, the specimens had a 30% increase in bending strength, allowing them to bend at very steep angles without breaking or cracking. The microstructure could be stabilized and the second phase precipitate particles could be released by using the right techniques and temperatures during annealing heat treatment. The Al 7075 alloy's formability, ductility, and corrosion resistance were all improved by the annealing process(Malik Abbas et al. 2023).

Zhang examined the effects of HFIR treatment on the 2A12 aluminium alloy's microstructure, average micro strain, dislocation density, nano microhardness, tensile strength, and corrosion behaviour. It was successful in creating an SPD layer. The average grain size of the top surface shrank as static pressure rose. With an increase in static pressure, there is an increase in nano microhardness, elastic modulus, and tensile strength. Among all the samples, including the HFIR-free one, the 2A12 aluminium alloy treated by 500N static pressure had the best corrosion resistance. The corrosion resistance was significantly increased by elements such tiny particle size, compressive residual stress, low surface roughness, and creation of dense passive film(H. Zhang et al. 2023).

Pant studied the CCR + AN alloy demonstrated outstanding HCF characteristics during annealing up to 100ºC. Precipitation interaction at grain boundaries is blamed for this improvement in fracture development resistance. The HCF strength gradually declines as annealing temperature increases from (100-250ºC), as a result of grain coarsening brought on by the recrystallization and recovery process at the aforementioned temperatures(Pant et al. 2023).

Panigrahi studied hardness measurements, tensile testing, XRD analysis, EBSD, and TEM characterizations; it was possible to determine how plastic deformation affected the mechanical and ageing properties of an Al-Mg-Si alloy (Al 6063 alloy) that had been subjected to rolling at both cryogenic and ambient temperature. Al 6063 alloy experiences extreme strain during plastic deformation, which results in ultrafine microstructures with enhanced hardness and strength. Due to the precipitation hardening and grain coarsening mechanisms, the ageing treatment of the highly deformed Al 6063 alloy greatly increased its strength and ductility. We evaluated the mechanical characteristics of cryorolled and room temperature rolled Al 6063 alloy(Panigrahi et al. 2009).

Luo studied Stir casting and subsequent cryorolling were used to create AlCoCrFeNi high-entropy alloy particles (HEAp)-reinforced aluminium matrix composites (AMCs). At ambient temperature (298K) and cryogenic temperature (173K), the tensile mechanical characteristics of the HEAp/AMCs were studied. Scanning electron microscopy (SEM), electron backscatter diffraction, and transmission electron microscopy (TEM) were used to examine the microstructures of the HEAp/AMCs. The tensile test findings demonstrate that the ultimate tensile strength and elongation of HEAp/AMCs sheets are greater at cryogenic temperatures than at normal temperature. The ultimate tensile strength of 3 wt pct HEAp/AMCs is improved from 204 to 251 MPa at cryogenic temperatures. The coefficient of thermal expansion mismatch reinforcement and dislocation reinforcement increase the strength of the HEAp/AMCs at cryogenic temperatures. In the cryogenic environment, the HEAp/AMCs exhibit a greater elongation, with a larger length-diameter ratio along the tensile direction. The molecular dynamics modelling of void nucleation in aluminium alloy deformed at 298 K and 173 K demonstrates that at cryogenic temperatures, the void nucleation threshold is larger and the nucleation rate is slower, contributing to the increased elongation of the HEAp/AMCs.Paul et at (Paul et al. 2023) explore the influence of heavy cryo-rolling (CryoR) (90% thickness reduction) on the microstructure, texture, and tensile characteristics of an exceptionally low stacking fault energy (SFE) Co20Cr26Fe20Mn20Ni14 high entropy alloy (HEA) was studied. To emphasise the effect of CryoR, comparisons with other extensively cold-rolled (CR)/cryo-rolled materials were also given. CryoR caused heterogeneities, shear bands, deformation twins, stacking faults, and a deformation-induced nano-lamellar structure with a spacing of 35 8 nm to develop. Surprisingly, the nano-grain size produced following CryoR was smaller than that of other low SFE alloys and at a far lower strain intensity. These findings revealed a synergistic effect of CryoR, enormous solid-solution formation, and extremely low SFE on severe grain refinement. CryoR also led in the formation of a strong brass texture (110112 >), which is comparable to that of other low SFE alloys. Because of the smaller nanostructure and increased stored energy for transformation, annealing led in recrystallization, precipitation, and dissolution of Cr-rich tetragonal phase precipitates in the CryoR material at lower temperatures. The presence of the precipitates hindered grain development up to 950°C, but the breakdown of the precipitates activated it above that temperature. Textures that were annealed preserved weak -fibre (normal direction (ND)//110>) components and a large proportion of random components, like other low SFE HEAs. Meanwhile, ultrafine microstructures and multistage strain-hardening produced an impressive ambient temperature strength-ductility (1025 MPa-20%) combination in CryoR and annealed HEA(Luo et al. 2023).

Longjian Li studied Cu-1Cr-0.2Zr (wt%) alloys with trace Mg element (0.05 wt%) were synthesized in this work using a two-step cryorolling and ageing (CRA) procedure. The effects of the two-step CRA and Mg element on the microstructure, mechanical characteristics, and electrical conductivity were studied. In the Cu-Cr-Zr-Mg alloys exposed to the two-step CRA procedure, high-density deformation twins and dislocations were detected. The widths of deformation bands and twins of the two-step CRA Cu-Cr-Zr-Mg alloys reduced by 11.5% and 34%, respectively, as compared to the Cu-Cr-Zr alloys subjected to two-step RTRA. The high-density dislocations in the two-step CRA Cu-Cr-Zr-Mg alloys gave the precipitates additional nucleation sites during the following ageing process. Fine precipitates were found at the grain boundaries and twin borders in the two-step CRA Cu-Cr-Zr-Mg alloys, despite their presence inside the subgrains and twins. The tiny precipitates (5.9nm) successfully prevented the mobility of dislocations, improving the performance of Cu-Cr-Zr-Mg alloys. The enhanced electrical conductivity was attributed to the removal of Cr and Zr elements from the copper matrix during the ageing process. The high tensile strength of 629 MPa and electrical conductivity of 79.66% IACS (International Annealed Copper Standard) were concurrently attained in this study thanks to the synergistic impact of the Mg element and the two-step CRA method(L. Li et al. 2023).

Prosenjit Das studied an experimental assessment of the 7075 Al alloy's yield strength, tensile strength, and impact toughness. For quasi-static crack formation simulations employing Charpy impact energy as the crack growth criterion for both bulk and ultrafine-grained materials, the extended finite element method (XFEM) has been adopted(Das et al. 2012).

Alloy 7075 Al (UFG). At cryogenic (liquid nitrogen) temperature, the 7075 Al alloy is rolled for various thickness reductions (40 and 70%), and its mechanical properties are investigated using tensile and Charpy impact testing. Field emission scanning electron microscopy (FE-SEM) was used to characterize the alloy's microstructural composition. Rolling the aluminium alloy at a cryogenic temperature prevents dynamic recovery, and dislocation cells created during processing become fully formed ultrafine grains (600 nm) with a thickness reduction of 70%.The crack growth criterion's influence energy utilizing the Griffith energy concept under quasi-static loading conditions. XFEM use ABAQUS Software (Version 6.9) to carry out the simulations of elastic-plastic ductile fracture. For modeling cracks to simulate a fracture based on the partition of unity notion, two different types of functions are employed. The region behind the crack tip is modeled by a discontinuous function, whereas the crack tip is modeled by a near-tip asymptotic function. This enables the fracture to be explicitly represented without meshing the crack surfaces, making it possible to conduct crack propagation simulations without the requirement for re-mesh. For a few real-world crack situations, strain energy release and stress distribution are discovered ahead of the fracture tip. The numerical examples show that successful grain refining has significantly improved the crack development characteristics of UFG 7075 Al alloy when compared to its bulk form.

Das investigate the impacts of cryorolling and the ideal heat treatment (short annealing plus ageing) on the tensile and impact-toughness behaviour of Al 7075 alloy have been examined. At cryogenic (liquid nitrogen) temperature, the Al 7075 alloy was rolled for distinct thickness reductions (40% and 70%), and its Tensile testing, hardness testing, and Charpy impact testing were used to examine mechanical qualities. Field emission scanning electron microscopy (FE-SEM) was used to characterize the alloy's microstructure. According to its FE-SEM micrographs, the cryorolled Al alloy reveals an ultrafine grain structure after a 70% thickness reduction. It has been found that, compared to the starting material, the yield strength and impact toughness of the cryorolled material have risen by 108% and 60%, respectively. The cryorolled Al alloy has higher tensile strength and impact toughness as a result of grain refinement, the creation of ultrafine grains by numerous cryorolling passes, and grain fragments with high angle boundaries. The ductile to brittle transition may be seen in scanning electron microscopy study of the fracture surfaces of impact tests performed on the samples in the temperature range of 200ºC to 100ºC.Cryorolled samples were aged at 140ºC and 120ºC after short annealing for 5 minutes at 170ºC and 150ºC for both 40% and 70% reduced samples. The combined effects of brief annealing and ageing increased the ductility and strength of cryorolled samples, which is attributable to subgrain coarsening and precipitation hardening respectively. On the other hand, the high strain rate involved in impact loading has reduced the impact strength of the cryorolled aluminium alloy(P. Das et al. 2011).

Marnette studied that Rolling was used to create ultrafine-grain aluminium sheet at both cryogenic (CR) and ambient temperatures (RTR). Commercial purity aluminium plate was 80% thinner after 30 passes going from a starting material thickness of 10 mm to a finished thickness of 2 mm. Total elongation was greatly reduced while tensile stress and strength were markedly raised. It was discovered that both materials can support large localized strains in the neck, resulting in a high reduction in area, although having modest tensile elongation. In bending operations, the material's formability was further examined. Pure bending tests revealed homogenous forming behaviour for both materials and a minimum bending radius of 6 mm (CR) and 5 mm (RTR) for both materials. The cryo-rolled material displayed strain localizations over the final radius and sample kinking during V-die bending. Ultra-fine grained and low ductile sheet metals can be roll formed into basic section shapes with small radii using commercial roll forming equipment, even if the overall elongation in tension is near to zero, causing early failure in V-die bending(Marnette et al. 2014).

Lingling Song studied AA1050/AA6061 multilayer composites were effectively created by fusing ARB with CR, then the composites underwent an ageing process to further enhance their UTS. The creation of multilayer metallic composites has been proposed as a new processing technique combining ARB and CR. The UTS of the A5 sample is 252 MPa while that of the C2 sample is 310 MPa under the same equivalent strain. As a result, the subsequent CR can greatly enhance the mechanical characteristics of multilayer composites made of AA1050 and AA6061. After peak ageing treatment at various temperatures the UTS of AA1050/AA6061 multilayer composites is further enhanced, with the most striking improvement occurring at 100°C(Song et al. 2023).

Shanmuga sundaram studied The 2219 Al alloy was cryorolled (85% thickness reduction and true strain of 2), annealed at 175 C for 3 minutes, and aged at 125ºC for 8 hours to produce a UFG microstructure with improved mechanical properties (YS of 485 MPa and UTS of 540 MPa with a tensile ductility of 11%). Cryorolling produced precipitation kinetics that were faster (8 h as opposed to 24 h) and had a lower ageing temperature (125ºC as opposed to 190ºC) than the standard T87 temper. Table 2 shows the effect of cryorolling on Tensile Testing with different parameters.Figure 5 indicate the Tensile properties comparison of CR and RTR Material at % thickness reduction at various temperature limits(Shanmugasundaram et al. 2006).

TABLE 2. Effect of cryorolling on Tensile testing of alloy.

Sr.No	Material	Processing condition	YS (MPa)	UTS (MPa)	% Elongation	Ref.
1	AA2219 alloy	Peak aged (T87)	393	475	10[a]	(Shanmugasundaram et al. 2006)
		As cryorolled (CR)	480	522	6[b]	
		CR + 175°C—3 min	460	496	8[b]	
		CR + 175°C—3 min+ 125ºC—8 h	485	540	11[b]	
		CR + 125°C—8 h	472	527	10[b]	
2	AA5052 alloy	Orientation 0°	76.2	177.4	4.32	(Chandra Sekhar et al. 2014a)
		Orientation 45°	124.5	190.6	5.18	
		Orientation 90°	105	178.8	4.8	
		Orientation average	107.5	184.35	4.87	
3	AA7075 alloy	Starting bulk alloy	260	510	15	(Prosenjit Das et al. 2011)
		40% room temp. rolled	395	517	12	
		40% cryorolled	430	530	10	
		70% room temp. rolled	510	525	8	
		70% cryorolled	540	550	5	
4	AA6061 alloy	Base material	230 ± 12	295 ± 10	13 ± 0.6	(Chandra Sekhar et al. 2014b)
		Room temperature	298 ± 18	313 ± 12	6.9 ± 0.2	
		Cryorolling temperature	366	385	6.3 ± 0.4	
5	AA6016 alloy	T6	296 ± 3	336 ±5	24 ± 2	(X. Zhang et al. 2023)
		High-pressure torsion (HPT	477 ± 4	584 ±3	3± 1	
		HPT + LL	459 ± 5	523 ± 10	36 ± 2	
		HPT + HS	399 ± 3	427 ± 10	25 ± 1	
6	AA7075-TaC alloy	0%TaC	107± 8	151±17	1.3±0.3	(Khalkho et al. 2023)
		+0.1%TaC	124±11	166± 21	1.7±0.2	
		+0.2%TaC	139± 9	179± 15	2.0± 0.4	
		+0.3%TaC	152± 12	190± 18	2.3±0.3	
		+0.4%TaC	163± 10	199± 22	2.5±0.5	
		+0.5%TaC	171± 15	205± 26	2.7±0.6	

continue ...

... cont.

7	Cu-Ti-Cr-Mg alloy	ST	262 ± 12	319 ± 30	46.8 ±0.3	(R. Li et al. 2023)
		RTR30	411 ± 1	442 ± 2	21.6 ±1.0	
		RTR60	506 ± 2	552 ± 7	16.3 ±0.3	
		RTR80	560 ±11	605± 2	14.6 ±0.1	
		RTR90	588±13	634± 3	15.6±0.5	
		CTR30	474±10	513±1	20.3±0.6	
		CTR60	568±13	627 ±11	16.2 ±1.8	
		CTR80	676±10	702±14	14.6 ± 0.4	
		CTR90	723±6	796± 3	16.0± 0.2	

a Measured on a gauge length of 50 mm.

b Measured on a gauge length of 25 mm.

HS- high-temperature short-time (HS) aging treatment

LL- low temperature long-time (LL) ageing treatment

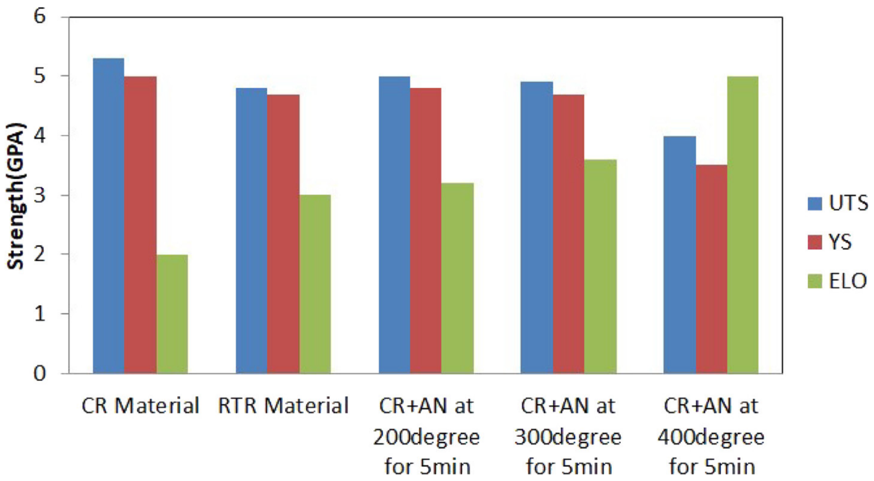

FIGURE 5. Tensile properties comparison of CR and RTR Material at % thickness reduction at various temperature limits. (“Mechanical performance and characteristics evaluation of material through Cryo rolling process A review.pdf,” n.d.)

CONCLUSION

A thorough analysis of the studies conducted by numerous researchers on the impact of cryorolling and post processing treatments on the microstructural, mechanical characteristics, and formability of different aluminium alloys is presented. Overall, cryorolling is a successful SPD technique to produce UFG structure in sheets of aluminium alloy with improved mechanical qualities when compared to traditional cold rolled conditions. The methods by which UFG structure was created in cryorolled samples were disclosed by microstructural evolution during the cryorolling process. Cryorolled aluminium alloys have ultrafine grain structure as compared to cold rolled samples.

Cryorolling aluminium alloys has been found to improve strength and hardness more than cold rolling due to the effective suppression of dynamic recovery that results in increased dislocation density. However, due to the sheets’ low ductility in their as-cryorolled condition, post-cryorolling procedures including warm rolling and low temperature annealing have been tried in an effort to create sheets with the best possible balance of ductility and strength.

SUGGESTIONS FOR FUTURE WORK

1. Cryorolled Al alloys could be used for hydroforming sheet metal components with more intricate geometrical features.
2. The current work can potentially be expanded to compare cryorolled 8011 Al alloys to typical cold rolled alloys and examine the impact of annealing temperature at various times.
3. The present work can be extended for the evolution of surface roughness value of cold rolled and cryorolled aluminium alloys.

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DECLARATION OF COMPETING INTEREST

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