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Effect on Material Properties of Aluminium Alloys After Cryogenic Rolling: A Review

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The market for lightweight automotive components is expanding rapidly. Most of these components are made using metal forming techniques to produce pieces that are lightweight, strong, and rigid. The majority of rolling operations are used to increase the ductility and strength of the material. To change the rolling surface during the deformation, an additional cross-rolling phase is added. The mechanical properties of the aluminum alloy sheet have been studied in this essay. The current situation, recent advancements, and anticipated future orientations of the subjects are the main issues of the article. This study examines how well various rolling methods—including room temperature and cryogenic rolling—perform on various materials found in the literature.

Keywords: aluminum alloys; Cold rolling; Cryorolling; Hardness; Tensile properties.

1. Introduction

Rolling reduces the thickness of the material. One roller rotates clockwise while the other rotates counterclockwise during rolling, as seen in fig. 1. The space between rollers should be smaller than the material's thickness while forming it into a useful component. Sandwiching metal between two rollers causes it to be crushed and subjected to friction, which causes the metal to thin and lengthen. Rolling is an advanced metal forming technique that creates more accurate and longer cross sections out of big bulk materials.

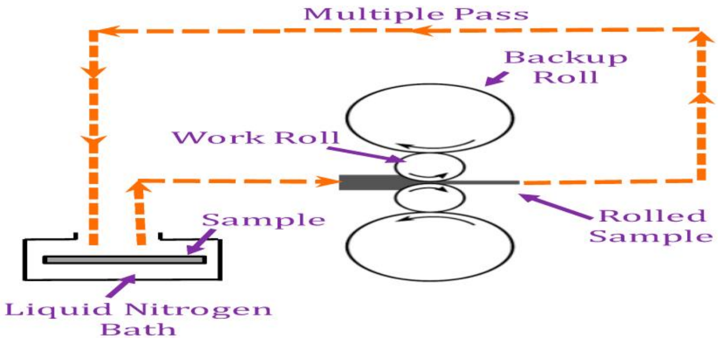

Figure 1: Schematic showing conventional rolling and cryogenic rolling[1]

Figure 2 shows the process. When a manufacturing operation is carried out at a temperature that induces refraction, it is known as cold rolling. Cold rolling is mostly used to produce small, extremely durable parts. Unlike hot rolling, cold rolling does not reduce thickness. Annealing, often known as cold rolling, is a process used to increase the ductility of steel by rolling below recrystallization. High strength and superior surface polish are provided by cold rolling processes. Cold rolled metal has been used to create bars, strips, rods, and sheet metal because of its low torsional resistance and buckling.

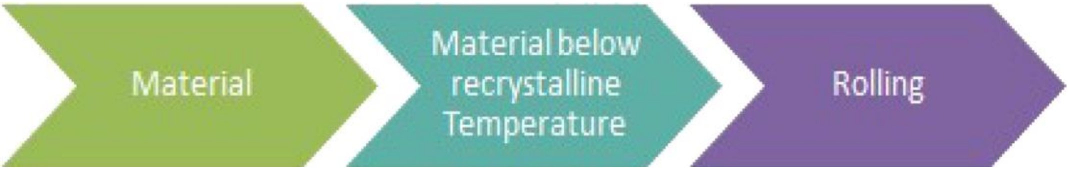

Figure 2. Flow diagram of cold rolling process.[1]

A kind of severe plastic deformation method called cryorolling, or cryogenic rolling, entails deforming a material at cryogenic temperatures [2]–[5]. A schematic diagram of the cryogenic rolling and traditional cold rolling procedures employing a two high rolling machine is shown in Figure 3. It is well known that many materials, particularly aluminum alloys, have better mechanical qualities when rolled at cryogenic temperatures. The technique of cryorolling entails bringing the material down to cryogenic temperatures, which are often less than -196°C, then rolling the material while keeping it at this temperature. The material becomes harder and more resilient as a result of the reduction in grain size brought about by the cryogenic temperatures.

One of the possible methods to produce nanostructured bulk materials from their bulk equivalent at cryogenic temperatures—roughly -196°C for liquid nitrogen is cryogenic rolling, or cryorolling, as it is depicted in Figure 4. Most of these techniques necessitate significant plastic deformations, or strains significantly greater than unity. Because the dynamic recovery is suppressed during cryorolling, the deformation in the strain-hardened metals is maintained. A cryorolling process flow diagram is displayed in Fig. 4. To reach the desired thickness, sheets are rolled at room temperature in several passes using conventional cold rolling (CCR) [4].

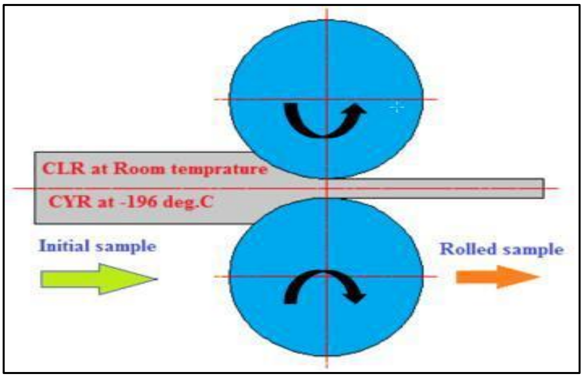

Figure 3: Schematic showing conventional rolling and cryogenic rolling[2].

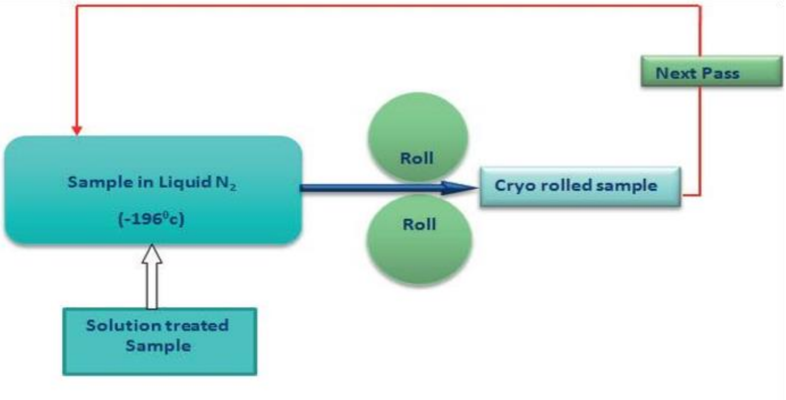

Figure 4: Flow diagram of cryorolling process.

Cryorolled aluminum alloy sheets that are low-temperature annealed (to prevent a large loss of strength) may produce sheets with an excellent blend of and formability. The breadth of uses for aluminum alloys and other sectors is anticipated to grow as a result.[5]

The growing demand for more fuel-efficient cars to lower energy consumption and air pollution is a researched concern for the automotive industry by Satish et al. [6]. Aluminum is the perfect material to replace heavier materials (like steel or copper) in cars in order to meet the automotive industry's demand for weight reduction because of its unique qualities, which include its high strength stiffness to weight ratio, good formability, good corrosion resistance, and recycling potential.

According to Hai Liang Yu et al. [7], there has been a noticeable rise in interest in ultrafine-grained (UFG) materials. The primary focus of this review is on the use of special rolling techniques to improve the mechanical characteristics of UFG metal sheets. Among these techniques are skin-pass rolling, asymmetric rolling, cryorolling, and cross-accumulative roll bonding. The procedures also involve a combination of processes including combined high-pressure torsion and rolling, equal channel angular press and subsequent asymmetric rolling, and combined accumulative roll bonding and subsequent asymmetric rolling. We also discuss the main mechanisms by which the special rolling processes linked to the higher ductility of

UFG materials.

Feyissa et al.'s study [3] revealed that Al-Mg alloys are a special class of materials because Al alloys have desirable qualities like high strength, good formability, and superior corrosion resistance. These properties make Al alloys suitable for a variety of applications in the chemical, automotive, aerospace, and marine industries. Due to the relatively large (>3%) Mg content as an alloying element, high mechanical strength is mostly acquired via solid solution strengthening and dispersion hardening. It can also be strengthened through work hardening.

Zhao et al.'s study [8] Alloys with subgrain or grain structures that are refined to one micron or less in thickness generally have high strengths but low tensile ductility. Historically, attempts to make them more ductile have usually led to a loss of strength. We have developed a workable process to yield a 2024 Al alloy that has outstanding ductility and high strength. The process consists of three steps: solution-treatment to partially dissolve T-phase particles, cryo-rolling to form a fine-structure with a high density of dislocations and submicrometer subgrains, and aging to produce highly dispersed nano-precipitates. It was demonstrated that the remaining T-phase particles significantly aided in the buildup of dislocations during cryo-rolling, which in turn promoted the precipitation of nanosized S′ precipitates with an interparticle spacing of only 10–20 nm.

Material scientists are interested in improving the mechanical characteristics of aluminum alloys. Severe plastic deformation procedures can increase the strength of ductile materials. These are standard metal forming procedures where parent materials undergo exceptionally high strain to create Ultra Fine Grain Structures (UFGS) with better strength, albeit at the expense of the material's ductility. Among them are Cryogenic rolling (CYR), High Pressure Torsion (HPT), Accumulative roll-Bonding (ARB), and Equal Channel Angular Pressing (ECAP).

Kim et al[9] studied Grain refinement and the formation of dislocation cells result from the massive shear strain of high-pressure torsion, which decreases the ductility of the alloy and enhances its strength. Solute migration, brittle intermetallic complex dissolution, and matrix-generated nanoparticulate precipitation are all accelerated by deformation and frictional heat. These solute migration processes contribute to the improvement of both strength and ductility by simultaneously inducing precipitation hardening and brittle phase dissolution. Consequently, the high-pressure torsion-processed aluminum 7075 alloy exhibits increased ductility and strength compared to its original state. This discovery illustrates how treating metallic alloys through high plastic deformation produces microstructural alterations that greatly enhance the mechanical characteristics of nanocrystalline materials.

The mechanical properties and microstructural evolution of the lightweight AA2050 Al-Cu-Li alloy developed by Jagadeesh et al. [10] have been documented. The production process involved two stages: artificial aging at 150 °C and multi-directional forging (MDF) at 170 °C. Systematic EBSD analysis conducted after 12 rounds of MDF revealed a considerable reduction in grain size, from 74.3 12 to 22.1 2.8 m. Dynamic recrystallization of deformation bands into subgrains has allowed for grain refining. TEM results show that peak aged MDF treated samples have large dislocation clusters and deformation bands coupled with a notable amount of fine precipitates. Owing to lattice strain that is formed on MDF, peak shifts and fluctuations in peak intensities are seen by XRD analysis. Significant gains in microhardness and strength were observed following the 12th MDF pass, at a negligible cost in ductility. Additionally, samples that had been aged in MDF demonstrated improvements in microhardness and strengths. Experimental results show the combined effect of precipitate hardening, strain hardening, and grain size reduction on material strength. Combining MDF with artificial aging may significantly increase the strength and ductility of AA2050.

The mechanical characteristics and EBSD of cryorolled LM6 Al alloy were investigated by Rawat et al. [11]. Solution-treated (ST) alloy was cryorolled to reduce thickness differences by up to 50%, 75%, and 90%.The impact of CR on the microstructure of the LM6 alloy was investigated using EBSD and TEM microscopy methods, the tensile test, and hardness measurements. The mechanical qualities of the CR LM6 Al alloy are better than those of the ST LM6 Al alloy. The findings demonstrated that the average kernel misorientation and the percentage of low angle grain boundaries increased together with the thickness reduction %. The LM6 Al alloy that has undergone CR processing displays enhanced mechanical properties when compared to all sample conditions, indicating the beneficial effects of grain refinement.

M. Tiryakioğlu et al [12] Vickers hardness, yield stress, and tensile strength were analyzed by combining data from two different studies utilizing a rectilinear forging and 7010 alloy plate.The hardness-yield stress values from the two studies overlapped, suggesting a possible fundamental relationship.Shaw and DeSalvo's constraint factor was found to be the most compatible when constraint factors obtained from contact mechanics models were compared to the slope for the hardness-yield stress data.The y-intercept of the hardness-yield stress relationship was explained by the work hardening that takes place during Vickers testing. The equation that was found to fit the hardness-yield stress data for 7010 plate and forgings also gave a very reasonable fit to a third independent study. Furthermore, an empirical formula was developed to represent the relationship between hardness and tensile strength.

Xiong et al [13] examined During the cryorolling process, high-density dislocations, deformation twins, and deformation-induced martensites were consistently observed in the deformation-induced martensite transition and the ensuing deformation microstructure. After the strain, the deformation microstructure's dislocation density grew closer to saturation state, and the volume % of deformation twins and martensites caused by deformation increased substantially. At 70% strain, the original austenite completely transformed into martensite. One additional increase in strain to 90% would refine the martensitic lamellae to a nanoscale. Furthermore, the degree of deformation resulted in a discernible improvement in the cryorolled SS's strength and hardness and a significant decrease in its elongation. The cryorolling resulted in a change in the tensile fracture morphology from a normal ductile rupture to a quasi-cleavage and ductile fracture combination.

Changela et al [14] Ultrafine-grained materials offer many structural and functional applications, but their mechanical properties have not been explored as much as those of coarse-grained materials. The current study looked at how rolling AA 3003 alloy and pure copper at room temperature and cryogenic temperatures affected their fracture behavior and mechanical properties. The thicknesses are obtained by rolling both materials to a thickness of 1 mm and 2 mm, respectively, with real plastic stresses of 1.09 and 0.40. The deformed samples are characterized using the tensile test, the hardness test, and the X-ray diffraction analysis. 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 (-196 °C) suppresses dynamic recovery, making it more difficult for dislocations to move, which increases dislocation density. When compared to materials with higher stacking fault energies (AA 3003), 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 [15] The AA 6061 alloy exhibits uneven total elongation, while the AA 5083 alloy exhibits the conventional trend of increasing ductility and decreasing strength with increased annealing temperature.

Ravi Kumar et al [1] The aforementioned study examined cryorolled aluminum alloy sheets' formability under warm forming circumstances. The two aluminum alloys that the researchers were primarily interested in were AA 5083 and AA 6061. These alloys underwent heated forming tests after being cryorolled to various thickness reductions.

The study's findings demonstrated that, in comparison to their non-cryorolled counterparts, cryorolled AA 5083 and AA 6061 alloys demonstrated better formability under warm forming circumstances. The creation of a fine and uniform microstructure as a result of the cryorolling technique was credited with improving the formability.

Additionally, the study discovered that the AA 6061 alloy's formability increase was more noticeable than that of the AA 5083 alloy. This was explained by the fact that the AA 6061 alloy had a higher work hardening rate, which improved the material's deformation and flow during heated forming.

Additionally, the study demonstrated that the formability of the aluminum alloys in warm forming was influenced by the degree of thickness reduction during cryorolling. Because a finer microstructure was formed, higher thickness reductions enhanced formability, whereas smaller thickness reductions only slightly affected formability.

The study's overall findings indicate that cryorolling can greatly increase an aluminum alloy's formability under heated forming circumstances. The employment of cryorolled aluminum alloys in the automotive and aerospace industries, where heated forming is frequently employed to produce complicated components, may be impacted by this.

Nikhil Kumar et al [16] 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 300 °C 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 250 °C and 250-300 °C, 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 150 °C 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 350 °C have outstanding corrosion resistance.

Jayaganthan et al [2] 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.

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 250°C, 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

Rao et al [3] 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.

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 et al [2] 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.

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 250°C, 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.

Jayaganthan et al [17] Examine the microstructural alterations that result from cryorolling the Al 5083 alloy. After varying degrees of thickness reduction using cryorolling, the researchers analyzed the microstructure of the alloy using a variety of characterization techniques.

The study's findings demonstrated that cryorolling increased the material's density of dislocations significantly, which raised the material's strength and hardness. The dislocation density rose in tandem with the degree of thickness reduction, the researchers found.

The investigation also shown that cryorolling improved the material's microstructure by reducing the size of its grains and subgrains. The creation of deformation bands during cryorolling, which resulted in the development of new grains with lower diameters, was credited with this refinement.

Additionally, the researchers noticed that the cryorolled material had anisotropic properties, meaning that the mechanical properties of the material were significantly influenced by the direction in which it was rolled. The researchers hypothesized that the dislocations and grains' alignment along the rolling direction may be the cause of this anisotropy.

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.

Shunmugam et al [18] Examine the changes in aluminum and its alloys' microstructure that occur during cryo-severe plastic deformation and post-deformation annealing. The microstructure of several aluminum alloys was examined by the researchers using a variety of characterization methods following cryo-severe plastic deformation and post-deformation annealing.

The study's findings demonstrated that cryo-severe plastic deformation significantly improved the alloys' microstructure by reducing the size of their grains and subgrains. The researchers noticed that the grain refinement became more noticeable as the degree of deformation rose.

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 et al [19] examined After being annealed, the 2195 Al-Cu-Li alloy plates underwent ageing treatment for varied periods of time at 175 °C. Next, they spent two hours in a solid solution at 540 °C. In contrast to the as-rolled sample, the heat-treated specimen's tensile strength and ductility both rose, despite the cryogenic rolling sample's anomalously higher yield strength.

Vineet Kumar et al [20] EBSD and TEM are used to characterize the microstructure of the cryorolled (CR) and room temperature rolled (RTR) 6082 Al alloy with different thickness reductions, such as 40%, 70%, and 90%. These studies focused on grain refinement, grain fragmentation, high angle boundaries, and the formation of ultrafine grains. Because of its higher tensile strength, CR alloy has superior mechanical properties compared to RTR alloy.

Singh et al [21] 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.

The impact toughness behavior of aluminum 5083 alloy during cryorolling and annealing is examined in this research. Transmission electron microscopy and scanning electron microscopy were also used to examine the alloy's microstructures.

The outcomes demonstrated that the alloy's impact toughness increased as a result of cryorolling and annealing. Following the treatment, the alloy's microstructure revealed the presence of fine grains and a decrease in the alloy's grain size.

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 et al [4] 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.

The study's findings demonstrated that, in comparison to traditional rolling, cryorolling created a finer and more uniform microstructure in the aluminum sheets, improving their strength and hardness. But compared to traditionally rolled sheets, the cryorolled sheets had less ductility and hardness. Conversely, heated forming preserved identical strength and hardness but created better ductility and toughness than standard forming.

The authors also looked at the effects of combining warm forming with cryorolling and discovered that this combination improved the mechanical properties of the aluminum sheets in a synergistic way. While the warm-formed sheets demonstrated better ductility and toughness, the cryorolled sheets displayed higher strength and hardness.

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.

Jayaganthan et al [22] 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.

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 were affected by the cryorolling strain, with a higher strain resulting in a faster rate of precipitation.

The paper also addresses the mechanisms—such as the higher solute atom diffusion rate and the increased number of nucleation sites—that underlie the improved precipitation kinetics in the cryorolled alloy. The precipitation behavior of Al 7075 alloy can be effectively controlled by cryorolling, according to the authors, which can enhance the alloy's mechanical qualities and structural performance.

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.[23] 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 et al [24] 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.

Panigrahi et al [25] 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 300 °C for 5 min.

Krishna et al [26] studied distinct temperatures, namely 28 °C (301 K) and 196 °C (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.

Taylor et al [27] studied the microstructure, sheets of precipitate-hardenable 2024 aluminium were rolled at liquid nitrogen temperature. differing aging/heat treating techniques have 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 150 °C. 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.

Effect of Cryorolling on Hardness:

The goal of several recent research projects has been to increase the ductility and strength of severely deformed age-hardenable aluminum alloys. For various alloys and characteristics, the hardness of CR and RTR samples has been investigated. The hardness data of the Al 7075 alloy samples (ST, CR, and RTR) compared to ageing time of up to 70 hours after being aged at 140°C. For ST samples, there is a notable increase in hardness up to 35 hours (71% increase), after which it diminishes. The CR and RTR samples, on the other hand, show the opposite trend, with hardness decreasing over time. It might be the result of the recovery effect, which happened when the CR and RTR samples aged over time at a high temperature. 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 [28]. 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 [29]. For AA5083 the 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 [30].

Wang et al [31] studied The performance and microstructure characterisation 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.

Zhang et al [32] 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.

Hao Gu et al [33] 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 superplasticity. 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.

Hanqing Xiong et al [34] 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.

Yuze Wu et al [35] 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 during annealing.

Yogesha K K et al [36] 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 175°C 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/m2). Through optical microscopy, X-ray diffraction, SEM fractography, and TEM, the microstructural characterisation of the deformed material was carried out, and it was connected with the tensile and fracture parameters of the alloy.

Shisen Yang et al [37] investigate cryorolling and room-temperature rolling were 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.

Tanya Verma et al [38] 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.

Jha et al [39] 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 analysed 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 et al [40] 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.

Moradpour et al [41] 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.

Feyissa et al [42] 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.

Cui et at [43] 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 100–300 °C for 1 hour, and then at 220 °C 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 programme 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 220 °C. 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.

Chen et al [44] 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.

Bobruk et al [45] 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.

Sahoo et al [46] 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 [47] 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. 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	[48]
		Annealing Temp. 150oC	139	
		Annealing Temp. 200oC	127	
		Annealing Temp. 250oC	116	
		Annealing Temp.300oC	94	
2	AA5083 alloy	Solutionised	95 ± 4	[23]
		RTR50	131 ± 4	
		LNR50	131 ± 7	
		RTR75	147 ± 3	
		LNR75	147 ± 4	
3	Al 7075 alloy	Starting bulk alloy	81	[49]
		40% room temperature rolled	137	
		40% cryorolled	155	
		70% room temperature rolled	160	
		70% cryorolled	137	
4	AA5083	Coldrolled+Annealed	85 HV	[30]
		Cryorolled	153 HV	
5	Copper	Cold Rolled (20%)	75.33	[50]
		Cryorolled (20%)	82.33	
		Cold Rolled (40%)	85	
		Cryorolled (40%)	90.8	

Effect of Cryorolling on Tensile Properties:

Navya et al [51] 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.

Abbas et al [52] 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 300°C 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 stabilised 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.

Zhang et al [53] examined the effects of HFIR treatment on the 2A12 aluminium alloy's microstructure, average microstrain, dislocation density, nanomicrohardness, 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 nanomicrohardness, elastic modulus, and tensile strength. Among all the samples, including the HFIR-free one, the 2A12 aluminium alloy treated by 500 N 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.

Pant et al [54] studied the CCR + AN alloy demonstrated outstanding HCF characteristics during annealing up to 100 °C. Precipitation interaction at grain boundaries is blamed for this improvement in fracture development resistance. The HCF strength gradually declines as annealing temperature increases from (100-250 °C), as a result of grain coarsening brought on by the recrystallization and recovery process at the aforementioned temperatures.

Panigrahi et al [55] 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.

Luo et al [56] studied Stir casting and subsequent cryorolling were used to create AlCoCrFeNi high-entropy alloy particles (HEAp)-reinforced aluminium matrix composites (AMCs). At ambient temperature (298 K) and cryogenic temperature (173 K), 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 [57] 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.

Longjian Li et al [58] 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.

Prosenjit Das et al [59] 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.

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 characterise 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 utilising 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 modelling 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 modelled by a discontinuous function, whereas the crack tip is modelled 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 et al [60] 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 characterise 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 200°C to 100° C.Cryorolled samples were aged at 140 °C and 120 °C after short annealing for 5 minutes at 170 ° C and 150 °C 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.

Marnette et al studied [61] 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 localised 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.

Lingling Song et al [62] 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.

Shanmuga sundaram et al [63] 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 125 C 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 (125°C as opposed to 190°C) than the standard T87 temper. Table 2 shows the effect of cryorolling on Tensile Testing with different parameters:

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]	[63]
		As cryorolled (CR)	480	522	6[b]	
		CR + 175°C—3 min	460	496	8[b]	
		CR + 175°C—3 min+ 125°C—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	[64]
		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	[49]

		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	[65]
		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	[66]
		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	[67]
		+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	
7	Cu-Ti-Cr-Mg alloy	ST	262 ± 12	319 ± 30	46.8 ±0.3	[68]
		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

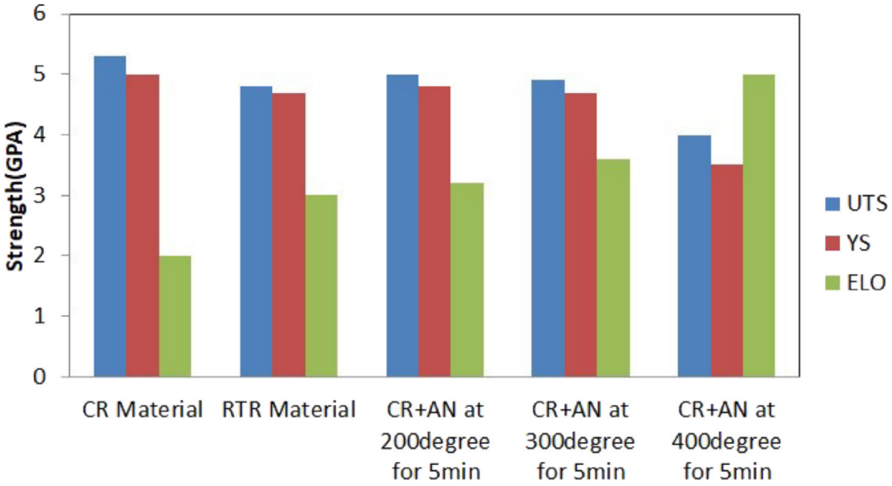

Figure 5:Tensile properties comparison of CR and RTR Material at % thickness reduction at various temperature limits.[69]

2. Conclusion

The study conducted by multiple researchers about the impact of cryorolling and post-processing treatments on the mechanical, microstructural, and formability characteristics of different aluminum alloys is thoroughly reviewed in this paper. Cryorolling is a successful SPD technology that produces UFG structure in aluminum alloy sheets with superior mechanical qualities when compared to traditional cold rolling conditions. The methods by which UFG structure was created in cryorolled materials were disclosed by microstructural evolution during the cryorolling process.

Since cryorolling efficiently inhibits dynamic recovery, which increases the density of dislocations, it has been found that cryorolling Al alloys improves strength and hardness more than cold rolling. However, due to the low ductility of the sheets in their as-cryorolled state, post-cryorolling methods like as warm rolling and low temperature annealing have been used in an effort to create sheets with the best possible balance of ductility and strength.

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