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# **Review on Advancement and Effectiveness of Cryogenic Treatment**

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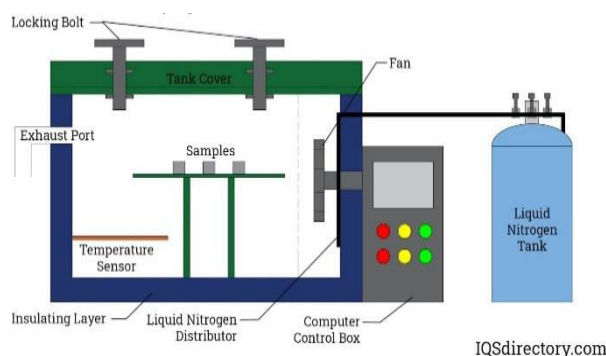
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**ABSTRACT:** Cryogenic treatment has emerged as a vital post-processing technique to enhance the mechanical, tribological, and microstructural properties of metal matrix composites (MMCs). This review explores the advancements and effectiveness of cryogenic treatment in improving the performance of aluminium-based and hybrid composites reinforced with ceramic particulates. The paper highlights the stir casting technique for composite fabrication and emphasizes how deep cryogenic treatment, typically at  $-196^{\circ}\text{C}$ , influences hardness, wear resistance, tensile strength, and dimensional stability by refining grain structure and precipitate morphology. Literature findings demonstrate that cryogenic treatment significantly improves microstructural integrity and mechanical reliability, as evidenced by XRD and SEM analyses. This paper consolidates current research trends and provides a foundation for future developments in high-performance cryogenically treated composite materials for aerospace, automotive, and industrial applications.

**KEYWORDS:** Cooling rate, Soaking time, and Stir casting.

## **I. INTRODUCTION**

Metal matrix composites combine different substances to enhance properties for specific applications. The need for lightweight materials with better performance in industries like automotive, aerospace, and nuclear energy has led researchers to focus on these composites, which address the limitations of conventional metals in strength, stiffness, and wear resistance. Stir casting techniques are commonly used to prepare metal matrix composites due to their simplicity and suitability for large-scale production, which reduces cost. Aluminium metal matrix composites, with their low density and high specific strength, are particularly attractive for weight-sensitive and stiffness-critical applications. Corrosion resistance is crucial for evaluating these composites as structural materials. As the demand for advanced engineering materials rises, metal matrix composites offer a reliable solution by enhancing the properties of parent materials while minimizing their limitations. Further, it improves composite properties, processes like heat treatment and cryogenic treatment are utilized, which enhances hardness and strengthens the material at a molecular level, resulting in improved durability.



**Fig.1 Cryogenic treatment.**



Composite materials are widely utilized in cryogenic applications due to their unique and customizable properties[18][20][25]. Metal Matrix Composites (MMCs) enhance performance across various fields, like toys to the automotive and aerospace industries, primarily due to their weight-saving benefits. To improve these composites further, various processes such as heat treatment and surface processing are employed. Figure 1 shows the Cryogenic Treatment, involving cooling materials to  $-196^{\circ}\text{C}$  with liquid nitrogen for 8 to 24 hours, plays a significant role[16]. This method is performed after quenching and is often incorrectly referred to as cryogenic tempering. Defects such as crystal and lattice imperfections, can emerge during metal production and heat treatment, negatively impacting mechanical properties. Cryogenic treatment weakens these defects by gradually cooling materials and then warming them back to room temperature, typically in a Cryochamber using gaseous nitrogen, which helps prevent thermal stresses. Changes in precipitation characteristics during cryogenic treatment are crucial for aluminum alloys and composites, relating closely to the type of alloy and heat treatment parameters[3][4][6][7][17][22]. However, these changes are less marked compared to those from aging treatments. Traditional microstructure analysis can be limited, but thermoelectric power (TEP) provides a sensitive measure of microstructural evolution. TEP is influenced by crystalline defects, making it a valuable tool for evaluating changes in materials treated with cryogenic methods.

**Factors affecting Cryogenic treatment:**

1. Cryogenic Temperature –  $-196^{\circ}\text{C}$  (77K) provides the best wear resistance, outperforming treatments at  $-110^{\circ}\text{C}$  or 189K.
2. Treatment Sequence – Applied immediately after quenching and before tempering to enhance martensitic transformation and carbide precipitation.
3. Cooling & Heating Rate – Should be  $1^{\circ}\text{C}/\text{min}$  to prevent cracking and thermal stress. Sudden immersion in liquid nitrogen must be avoided.
4. Soaking Period – 24 hours is optimal for most materials in deep cryogenic treatment (DCT), while shallow cryogenic treatment (SCT) requires only a few hours.

**Effect of Cryogenic treatment on Mechanical properties:**

1. Hardness: Increases due to martensitic transformation and precipitation of fine carbides in steels. Improves surface hardness in non-ferrous metals like aluminum and titanium.
2. Wear Resistance: Enhanced by reducing retained austenite and forming secondary carbides, making the material more resistant to abrasive wear. Beneficial in cutting tools, gears, and engine components.
3. Tensile Strength & Yield Strength: In steels, conversion of retained austenite to martensite increases tensile strength. Some materials may experience minor reductions in ductility.
4. Toughness & Impact Strength: Proper tempering after cryogenic treatment prevents excessive brittleness. Improves fatigue strength by reducing internal stresses.
5. Fatigue Resistance: Enhances due to stress relief and carbide refinement, increasing the lifespan of components under cyclic loading.
6. Dimensional Stability: Reduces internal stresses caused by machining or heat treatment, ensuring minimal distortion over time. Important for precision tools, aerospace, and automotive components. By optimizing cooling rate, soaking time, and post-treatment tempering, cryogenic treatment significantly enhances these mechanical properties, making materials more durable and reliable.

**II. LITERATURE SURVEY**

1. Abhay Shivaji rao Gore et.al., Study presents valuable insights into the machining of Al/SiCp composites using WEDM, highlighting the effects of cryogenic treatment and pulse duration on kerf width. The findings demonstrate that longer cryogenic treatment significantly improves kerf quality, while optimized pulse settings can reduce wire breakage and machining defects. The use of Response Surface Methodology effectively predicts kerf width, showcasing its potential for further research. Overall, the research contributes important data for advancing the machining processes in foundries. This work is a commendable step towards improving the efficiency and precision of composite material machining.
2. Mingli Zhang et.al., studied 15 vol% silicon-carbide particle-reinforced 2009Al composites, subjected to solution treatment, cryogenic treatment at  $-196^{\circ}\text{C}$ , and artificial aging at  $170^{\circ}\text{C}$  for varying durations.

Results showed that hardness increased with aging time, achieving a 2-4% enhancement after 20 hours due to cryogenic treatment. The changes in hardness were attributed to microstructural evolution in the aluminum matrix. TEP measurements effectively assessed precipitation characteristics. While tensile strength and elongation remained largely unaffected, yield strength increased by 16 MPa with cryogenic treatment before aging.

3. Ranjitha P et.al., The study investigates the effects of cryogenic treatment on AlSiC-B<sub>4</sub>C composites, prepared using the stir casting method. The composites were cryogenically treated at -196°C for 24 hours, improving hardness due to better wear resistance. As SiC content increased, hardness also increased, while the effect of B<sub>4</sub>C showed a peak at 2% before declining. Cryogenic treatment enhanced toughness, though tensile strength slightly decreased. The treated composites exhibited improved durability and mechanical properties, making them suitable for applications requiring higher wear resistance and stability.
4. A. Jeyachandran et.al., developed an Al6061-based hybrid composite reinforced with SiC and TiO<sub>2</sub> using the stir casting method, with reinforcement particles preheated to 550°C. Cryogenic treatment at -196°C for 20 hours modified the precipitate morphology, enhancing hardness and strength. Increased reinforcement content improved wear resistance, as TiO<sub>2</sub> acted as a lubricant, reducing both wear rate and friction. Compared to unreinforced Al6061 and composites, the hybrid composite exhibited superior mechanical and tribological properties. The findings highlight the benefits of cryogenic treatment and hybrid reinforcement in enhancing composite performance.
5. K. Thamizhmaran et.al., studied metal matrix composites prepared via stir casting with LM25 alloy as the matrix and commercial TiO<sub>2</sub> as reinforcement, varying the volume fraction from 5% to 20%. The TiO<sub>2</sub> particles, sized 30-50 µm, were preheated to 550°C to remove moisture before mixing with molten aluminum. For cryogenic treatment, LM25 alloy and LM25/TiO<sub>2</sub> composite samples were placed in a cryogenic chamber and gradually immersed in liquid nitrogen, reaching -196 °C for four hours. They were held at this temperature for various durations (1, 5, 10, 20, 30, 40, and 50 hours) before warming to around 25°C. This treatment changed the morphology of precipitates in both the alloy and composite, significantly improving the hardness of the MMCs, particularly due to the coarse eutectic β phase in the matrix. Hardness increased with the reinforcement volume fraction, although pure aluminum showed reduced effects from cryogenic treatment. Microstructural changes were also noted, as reflected in the X-ray diffraction (XRD) patterns.
6. Lijun Wei et.al., The study on 7075 aluminum alloy examined the effects of cryogenic treatment (CT) at different temperatures, including -196°C. CT improved the microstructure by dissolving coarse secondary phases and promoting uniform distribution of Mg, Cu, and Zn. It also reduced residual stress, enhancing dimensional stability. XRD analysis showed grain reorientation towards the (200) plane due to recovery and recrystallization. The optimal CT temperature for 7075 aluminum was found to be -120°C, balancing microstructural refinement and stress relief, making it suitable for high-performance applications.
7. Arun C Dixit, The study explores the effect of cryogenic treatment on Al7075-SiC-Gr hybrid composites produced via stir casting. Tensile strength and hardness improved with SiC reinforcement, peaking at 3.75% and 2.5%, respectively, but decreased at higher graphite content due to weak bonding. Cryogenic treatment enhanced corrosion resistance by reducing surface pits and cracks through eta-carbide precipitation. However, casting defects in 3.75% SiC-Gr affected its corrosion behavior. The findings suggest that cryogenic-treated composites are suitable for aerospace, automotive, and marine applications due to their improved durability and mechanical properties.
8. A. Jeyachandran et.al., The study investigates the sliding wear behavior of cryogenically treated Al6061 hybrid metal matrix composite reinforced with 2.5% SiC and 5% TiO<sub>2</sub>. The stir casting method was used for fabrication, followed by cryogenic treatment at -196°C for 20 hours. Wear tests were conducted using a pin-on-disc setup under different loads (3, 4, and 5 kg). The results showed that cryogenic treatment improved wear resistance by refining the microstructure and reducing material loss. TiO<sub>2</sub> acted as a lubricant, reducing friction and wear rate, while SiC enhanced hardness. SEM analysis confirmed an abrasive wear mechanism, with cryogenic-treated samples showing better performance than untreated ones.

9. Panchakshari H.V. et.al., conducted a study using  $\text{Al}_2\text{O}_3$  particles (30-50  $\mu\text{m}$ ) as reinforcement in composites, varying the content from 5% to 20% by weight. Liquid metallurgy was employed for fabrication, and the samples have undergone cryogenic treatment at  $-196^\circ\text{C}$  for 10 to 50 hours before being gradually warmed to  $+25^\circ\text{C}$ . This treatment significantly altered the microstructure of the metal matrix composites (MMCs), transforming the  $\alpha\text{-Al}$  phase to  $(\text{Mg}_{17}\text{Al}_{12})$  and reducing grain size. X-ray diffraction (XRD) analysis shows changes in diffraction peak intensity due to cryogenic treatment. Ultimate tensile strength (UTS) increased with treatment duration, peaking at 30 hours, after which effects diminished, and slight declines were noted due to saturation. Higher  $\text{Al}_2\text{O}_3$  content enhanced composite strength by promoting the formation of interfacial reaction products like  $\text{MgO}$  and  $\text{Mg}_2\text{Si}$ . Yield strength increased from 60 MPa in the as-cast condition to 160 MPa with  $\text{Al}_2\text{O}_3$ , and up to 185 MPa after cryogenic treatment. The cryogenic process improved hardness by about 10-15%, while overall hardness increased around 43% with higher  $\text{Al}_2\text{O}_3$  content. However, ductility decreased significantly by about 53% as  $\text{Al}_2\text{O}_3$  content increased from 0% to 20%.
10. The study by R.F. Barron (1982) examines the effect of cryogenic treatment on the wear resistance of 19 metals, including tool steels, stainless steels, and others. It compares the effects of 189 K ( $-84^\circ\text{C}$ ) and 77 K ( $-196^\circ\text{C}$ ) soaks. The results showed that tool steels exhibited the most significant improvement in wear resistance, especially at 77 K, due to better transformation of retained austenite to martensite. Stainless steel also showed improvement (up to 25%), while carbon steel and cast iron showed no significant change. The study concludes that cryogenic treatment enhances wear resistance, particularly for materials prone to retained austenite.

### III. RESULTS

Cryogenic treatment enhances the mechanical and tribological properties of various materials by refining microstructures and promoting precipitate formation. It is particularly effective in improving wear resistance, hardness, and corrosion resistance. Tool steels exhibit the most significant enhancements, while stainless and carbon steels show moderate to minimal effects. In metal matrix composites, such as aluminum alloys reinforced with ceramic particles, cryogenic treatment improves tensile strength, hardness, microhardness, and wear resistance by optimizing grain structure and aging behavior. It also contributes to improved dimensional accuracy in machining processes like WEDM. These enhancements make cryogenic treatment highly beneficial for applications in industrial, aerospace, and automotive sectors.

### IV. CONCLUSION

These findings confirm that cryogenic treatment is a valuable post-processing method for enhancing the mechanical, tribological, and corrosion properties of aluminum alloys and composites. This makes them highly suitable for demanding applications in aerospace, automotive, and other high-performance engineering fields.

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