

Investigation of microstructural and mechanical behavior on cryogenically treated Aluminium 7075 alloy

K Gnanasekaran¹, S Prathap Singh^{2}, G Ashwin Prabhu¹, D. Sakthivel¹, R Saron¹, and M. Sarath Bala¹*

¹Department of Mechanical Engineering, St. Joseph's College of Engineering, Chennai, Tamilnadu, India.

²Department of Mechanical Engineering, St. Joseph's Institute of Technology, Chennai, Tamilnadu, India.

Abstract. Aluminium (Al) 7075 alloy has been employed in defense and aerospace applications, as well as aircraft fittings. In this investigation, the Al7075 alloy was treated to cryogenic soaking treatment in the range from 2 to 6 hours, whereas the cryogenic soaking temperature was -196°C , a constant. The specimens were immersed in a liquid nitrogen storage reservoir with a controlled cooling temperature of -196°C . The cryogenically treated specimens are subjected to mechanical behaviour tests such as tensile, compression, impact, and hardness tests. Scanning Electron Microscope (SEM) revealed a comparison of the microstructure of the specimen before and after the experiment. The mechanical property of the Al7075 alloy material was enhanced because of grain enhancement through the cryogenic temperature controlled treatment. The grain refinement was the key factor for new grain boundary development in the boundary region, and this grain boundary development enhances mechanical strength in the Al7075 alloy.

1 Introduction

The exceptional corrosion resistance and strong mechanical strength of Al7075 make it stand out. Its formability, resistance to creep, and fatigue strength are all higher than those of regular Al. This alloy is commonly used as the matrix foundation material in many applications because of its low specific gravity and outstanding heat resistance; it finds importance in many different industries, including electronics, sports, and aircraft [1,2].

Rapid cooling down from the solution heat processing behavior temperature is a vital step in getting extraordinary strengths in precipitation-hardened Al alloys. While freezing is rapid and sufficient, it will progress to a greater power [3,4]. On the other hand, an additional disadvantage of quick cooling is the formation of residual tensions [5]. On the other hand, residual pressures have an undesirable impact on component belongings owing to deformation and dimensional fluctuation, and they can effect premature disaster. As a result,

* Corresponding author: prathap.singh50@gmail.com

reducing the residual stresses induced by quick quenching is crucial for improving the component's dimensional correctness. In order to lessen the residual strains that are caused by quenching in aluminum alloys, a substantial amount of research has been carried out. Some scientists have experimented with various quench environments, such as temperature controlled quench environment and temperature of quenching, to achieve the desired power [6.7].

Cryogenic treatment, a kind of special heat treatment, has significant applications in the ferrous alloys industry [8]. Nonetheless, it has been noted in certain research that cryogenic treatment is unable to directly produce the phase change in Al alloys. The alloy's mechanical characteristics can be altered as a result of the dislocations produced by the materials' thermal expansion and cold contraction, which can impact the precipitation of the strengthening phase [9]. Cryogenic treatment of samples increases the tensile capability of 2024 Al alloy by precipitating a finer and more evenly distributed phase, according to research by Araghchi *et al.* [10]. Thus, the precipitation of the strengthening phase through the influence of dislocations may be significantly impacted by cryogenic treatment.

In order to develop a suitable cryogenic treatment procedure, this research seeks to comprehend the impression of cryogenic management on the Al7075 alloy. The current study examines the impact of different cryogenic soaking times on Al7075 alloy and finds a direct relationship between soaking time, microstructural refinement, and mechanical enhancement, in contrast to earlier research that mostly dealt with steels and composites.

2 Constituents and Approaches

Al7075 was utilized in this learning, and it was cryogenically treated. The dimension of the used Al alloy was 15 mm diameter and 30 mm length. Al7075 was immersed in a temperature controlled liquid nitrogen tank at -196°C temperature, with soaking times ranging from 2 to 6 hours, and then gradually carried up to around $+25^{\circ}\text{C}$. A K-type thermocouple monitored the sample temperature and controlled a stepper motor to reduce it at a pace of 1°C per minute. The cryogenically treated Al7075 was then put through microstructural and mechanical behavior tests like hardness, tensile, compression, and impact.

Once the accomplishment of the cryogenic handling, an SEM was used to evaluate the impact of cryogenic soaking duration on the Al alloy. Initially, several types of emery paper were used to polish the microstructure specimen. After each polishing cycle, the surfaces were washed, dried, and wiped with a soft cloth. The microstructure of the cryogenic-treated material was discovered using an SEM agreeing to the American Society for Testing and Materials (ASTM) E3 criteria. Hardness is defined as the opposition to diffusion. It is recognized by appraising the depth of the indentation. The cryogenically treated Al 7075 was machined in agreement with the ASTM E92 standard. The Brinell hardness test was performed on samples using a 250 kg weight for 10 seconds.

The tensile test, which is also generally referred to as a tension test, was carried out with the assistance of a Universal Testing Machine (UTM). The cryogenically treated Al7075 alloy specimens were machined in compliance with ASTM E8. The supreme experiment load for the UTM was 100,000 N load application. The 5 N dislodgment had an accuracy of 0.1 mm, and the crosshead speed diversified between 0.1 and 500 mm/min. A compression experiment on the processed sample determines how materials respond to compressive loads. The specimen is squeezed and distorted at various stresses. At room temperature, compression tests were accomplished on an ASTM E9-machined cylindrical sample (25°C). It is conducted using a UTM with compressive load creating fixtures at a steady level of feed rate of 1 mm/mm. The load cell precisely monitored the movement of each sample. A material's ability to absorb energy during a fracture can be evaluated through the use of an impact test. By using it, one can ascertain if the substance in question is brittle or ductile. To

gauge impact strength, an impact experiment was performed using ASTM 370 impact test equipment.

3 Result and Discussions

The detailed results of the cryogenically treated Al7075 alloy at different soaking durations are discussed in this section. Figure 1 depicts SEM micrographs of Al7075 alloy subjected to varying cryogenic soaking times.

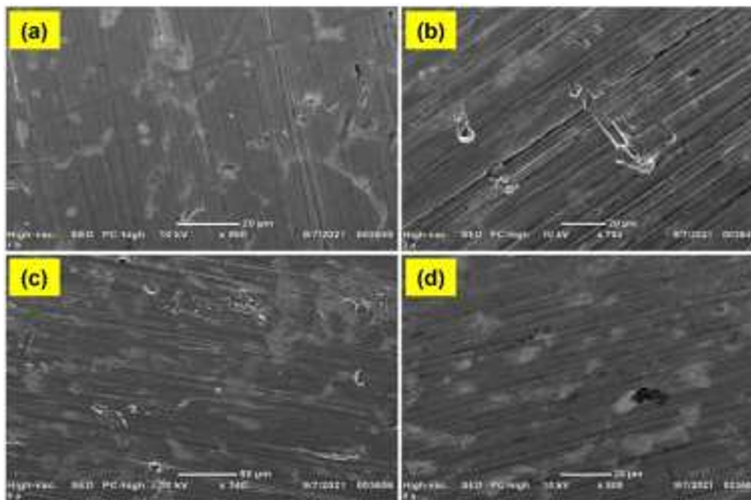


Fig. 1. SEM of cryogenically treated Al7075 alloy at different soaking duration of (a) 0 hours, (b) 2 hours, (c) 4 hours, (d) 6 hours.

Figure 1(a) shows the SEM image of the 0-hour cryogenically treated Al7075 alloy, and it revealed the coarse surface characteristics and an uneven distribution of intermetallic phases. Figure 2(a) shows the SEM image of the 2-hour cryogenically treated Al7075 alloy. After two hours of cryogenic treatment, the precipitates begin to redistribute more uniformly due to lattice contraction and increased dislocation mobility.

Figure 1(c) shows the SEM image of the 0-hour cryogenically treated Al7075 alloy. After four hours of soaking, the microstructure becomes more refined and homogenous, showing that precipitation hardening and dislocation pinning are effective. Four hours of soaking are required to achieve finer and more homogenous microstructure, indicating that precipitation hardening and dislocation pinning works. The image of the 6-hours cryogenically treated Al7075 alloy is plotted in figure 1 (d) as a SEM. The protracted soaking (6 hours) marks off slight coarsening of precipitates, which is a sign of a saturation level of microstructural refinement. Consequently, a 4-hour cryogenic soak offers the most optimum combination of strengthening on precipitation and stability of microstructure in Al7075.

The data in figure 2 shows the change in Brinell hardness of Al7075 alloy with the various cryogenic soaking time periods. The hardness also increases gradually with the time of cryogenic treatment. Untreated (0 hour) sample is the least hard as it contains coarse and non-uniform precipitates. Cryogenically processed Al7075 alloy (2 hours) has a BHN of 178. The maximal hardness is attained after 6 hours of soaking, when a more stable and refined precipitate distribution is created, resulting in increased resistance to plastic deformation. It was 30.95% more expensive than the standard Al alloy 7075. The increased grain refining enhances the material's hardness. The steady increase in hardness demonstrates that

cryogenic soaking enhances microstructural refinement and strengthening of the Al7075 alloy.

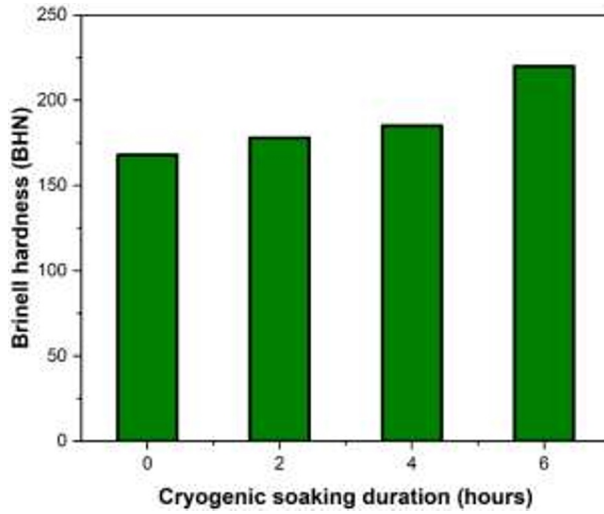


Fig. 2. Dissimilarity in Brinell hardness in regard to the different cryogenic soaking duration.

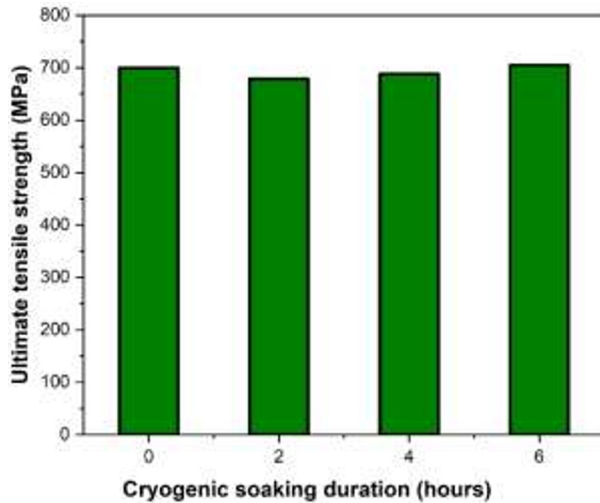


Fig. 3. Dissimilarity in tensile strength in regard to the different cryogenic soaking duration.

Figure 3 presents the dissimilarity in ultimate tensile capability of the Al7075 alloy with not the same cryogenic soaking durations. The untreated alloy has a baseline ultimate tensile strength of about 700 MPa. After 2 hours of soaking, ultimate tensile strength shows a modest drop, which could be due to initial precipitation rearrangement and the release of internal residual tensions. Ultimate tensile strength returns to close to previous value, when 4 hours of soaking is applied because of greater stability of the matrix and uniform precipitate dispersion. The final tensile strength after 6 hours only shows a modest increase in comparison to the untreated state, so that the prolonged soaking state results in more stable and refined morphology of the precipitate, which enhances load-bearing capacity. The trend suggests that cryogenic soaking is mainly an enhancement of hardness and microstructural

homogeneity with very slight alterations in ultimate tensile strength implying a tradeoff between stress reduction and strengthening through precipitation.

Figure 4 shows that the compression strength of the Al7075 alloy varies with the length of cryogenic soaking. The alloy in its untreated form has a minimum compression strength of approximately 580 Mpa. This is probably due to the first decrease of the internal residual tensions and a significant increase after 2 hours of soaking. Increased load-bearing properties and stable pinning of dislocation of the matrix are evidenced by the fact that the compression strength is steadily growing after 4 hours. The compression strength was observed to be the greatest after 6 hours of soaking. This suggests that the precipitate distribution becomes more compact and homogeneous with prolonged cryogenic exposure, making it more resistant to deformation under compressive loading.

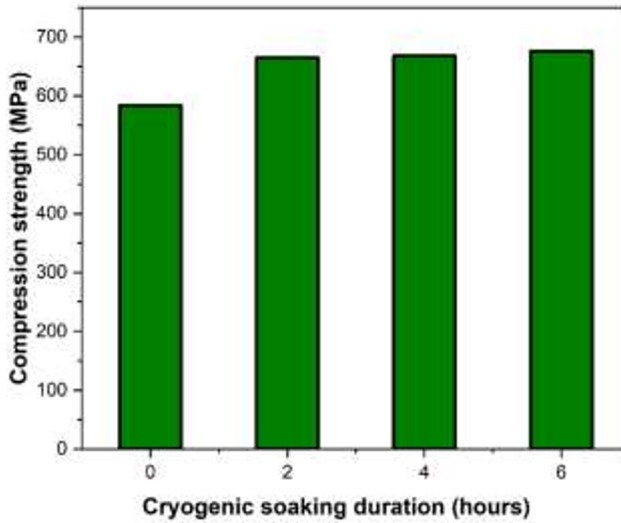


Fig. 4. Dissimilarity in compression strength in regard to the different cryogenic soaking duration.

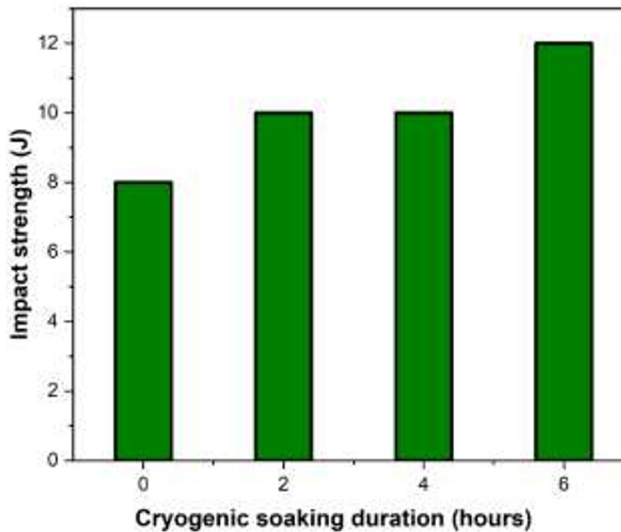


Fig. 5. Dissimilarity in impact strength in regard to the different cryogenic soaking duration.

Different cryogenic soaking lengths result in varying impact strengths of the Al7075 alloy, as shown in Figure 5. An impact strength of 8 J was measured for the untreated specimen after 0 hours of soaking. The impact strength increased by 25% from the untreated state to 10 J following a 2-hour cryogenic treatment. Even after soaking for four hours, the result was steady at 10 J. But after 6 hours of immersion, the specimen's impact strength increased to 12 J, 50% greater than the untreated sample. The consistent transition of retained austenite into martensite and the accompanying reduction in residual stresses are the causes of the progressive improvement in impact strength with soaking time. It seems that the best time to improve impact energy absorption capacities is with a 6-hour cryogenic immersion.

4 Conclusions

Cryogenic treatment significantly changed the microstructural and mechanical properties of the Al7075 alloy.

The SEM analysis showed that the grains were finer and the distribution of precipitates was more consistent after soaking for 6 hours.

After 6 hours of cryogenic soaking, the hardness of the alloy reached a 30.95% improvement compared to the untreated sample, and it grew consistently with the soaking period.

After long soaking, the ultimate tensile strength rose slightly, suggesting that the matrix was more stable and that the precipitates were distributed more evenly.

The compression strength peaked at 6 hours of soaking time, thanks to improved dislocation pinning and stress reduction, and it increased significantly thereafter.

There was a 50% improvement in toughness and energy absorption capabilities, as the impact strength went from 8 J (untreated) to 12 J (6-hour treated).

The improvement in mechanical properties is thought to be caused by the steady change of retained austenite into martensite, the reduction of residual stress, and the smoothing out of microstructure.

The ideal combination of hardness, toughness, and strength in the Al7075 alloy was found to be a cryogenic soaking time of six hours.

References

1. N. K. Singh, B. Sethuraman, Development and Characterization of Aluminium AA7075 Hybrid Composite Foams (AHCFs) Using SiC and TiB₂ Reinforcement. *Inter Metalcast*. **18**, 212 - 227 (2024). <https://doi.org/10.1007/s40962-023-01009-6>
2. N. K. Singh, S. Balaguru, P. Mehta, A. Kaimkuriya, A. K. Namdeo, R. K. Deb, Effect of Reinforcement on Micro Structural and Compressive Deformation Behavior on Closed Cell AA7075 Aluminium Foam. *Journal of Mines, Metals and Fuels*. **72(2)**, 179–187 (2024). <https://doi.org/10.18311/jmmf/2024/35988>
3. S. Pan, K. Jin, T. Wang, Z. Zhang, L. Zheng, N. Umehara, Metal matrix nanocomposites in tribology: Manufacturing, performance, and mechanisms. *Friction* **10**, 1596–1634 (2022). <https://doi.org/10.1007/s40544-021-0572-7>
4. M. Merisalu, L. Aarik, J. Kozlova, H. Mändar, A. Tarre, V. Sammelselg, Effective corrosion protection of aluminum alloy AA2024-T3 with novel thin nanostructured oxide coating. *Surface and Coatings Technology* **411**, 126993 (2021). <https://doi.org/10.1016/j.surfcoat.2021.126993>
5. S. Pan, J. Yuan, Michael P. Moodispaw, C. Linsley, J. Liu, Alan A. Luo, A. Taub, X. Li, Corrosion performance of nano-treated aluminum alloy A206 with TiC

nanoparticles. *Materials and corrosion*. **74(3)**, 419-429 (2023).

<https://doi.org/10.1002/maco.202213503>

6. J. Wang, J. Xie, D. Ma, Z. Mao, T. Liang, P. Ying, A. Wang, W. Wang, Effect of deep cryogenic treatment on the microstructure and mechanical properties of Al–Cu–Mg–Ag alloy. *J. Mater. Res. Technol. JMR&T*. **25**, 6880–6885 (2023).
<https://doi.org/10.1016/j.jmrt.2023.07.130>
7. X. Niu, Y. Huang, X. Yan, Z. Chen, R. Yuan, H. Zhang, L. Tang, Optimization of Cryogenic Treatment Parameters for the Minimum Residual Stress. *J. Mater. Eng. Perform.*, **27**, 3234–3238 (2018). <https://doi.org/10.1007/s11665-018-3400-0>
8. M. Jovicevi c-Klug, R. Rezar, Patricia Jovičević-Klug, B. Podgornik, Influence of deep cryogenic treatment on natural and artificial aging of Al-Mg-Si alloy EN AW 6026. *J Alloys Compd*. **899**, 163323 (2022).
<https://doi.org/10.1016/j.jallcom.2021.163323>
9. T. Hong, Y. Shen, J. Geng, D. Chen, X. Li, C. Zhou, Effect of cryogenic pre-treatment on aging behavior of in-situ TiB₂/Al–Cu–Mg composites. *Mater Char*. **119**, 40-46 (2016). <https://doi.org/10.1016/j.matchar.2016.07.012>
10. M. Araghchi, H. Mansouri, R. Vafaei, Yina Guo, A novel cryogenic treatment for reduction of residual stresses in 2024 aluminum alloy. *Mater Sci Eng*, **689**, 48-52 (2017). <https://doi.org/10.1016/j.msea.2017.01.095>