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CRYOGENIC HEAT TREATMENT ON NON-FERROUS ALLOYS– A REVIEW

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Abstract: **Cryogenic heat treatment process is well known for enhancing the mechanical properties of alloys having considerably low melting points and less weight. This sub-zero treatment process possesses various beneficial effects on the behavior and the microstructure of the material treated as well. Cryogenic heat treatment is an in-expensive process in comparison with the other heat treatment process undergone to enhance the core properties of the lightweight alloys. Cryogenic heat treatment hence finds the applications in many industries such as automotive, electronics, aerospace and defense. In the proposed review article, the post effects of the cryogenic heat treatment on various non-ferrous alloys were discussed. The non-ferrous alloys are taken into the account for the reviews are Aluminium, Magnesium and Copper alloys. Even though much detailing is remained to be learnt regarding the postal effects of the non-ferrous alloys undergoing cryogenic heat treatment.**

Keywords- **cryogenic heat treatment, magnesium alloy, copper alloy, aluminum alloy**

I. INTRODUCTION

Since, there are as many heat treatment processes in existence to influence the mechanical properties and the behavior of the materials as per the requirement in accordance with the application. Since there a number of heat treatment, every process is not applicable for every material. Heat treatment process need not be unilateral in its working temperature, sub-zero temperature are also implemented to attain utmost beneficial effects. Sub-zero heat treatments are invented mainly for the materials possessing low melting points. The most significant sub-zero temperature heat treatment is the cryogenic heat treatment. This cryogenic heat treatment is the process of dropping the material temperature of several degrees below zero which is otherwise called as sub-zero temperature. Typically, treatment below -80°C is called as Cryogenic Treatment. The common medium used to reduce the temperature of the test material to sub-zero level are dry ice, carbon-di-oxide, liquid nitrogen and helium. These agents can be used by either spraying or immersing. The most familiar and effective agent is liquid nitrogen by which the obtained lowest temperature of up to -192°C. The test material is drawn gradually to the lowest possible or required temperature and kept idle for few hours. Then, the material is brought back to the ambient temperature in a gradual manner. The Cryogenic Treatment plays a main role in the micro-structural arrangement whereas the reduction of temperature in sub-zero level, the major composition of Austenite is transferred to Martensite structure. It also leads to reduction in excessive thermal stress. The cryogenic treatment process various effects according to the temperature maintained. This proposed article showcases the various postal effects of cryogenic treatment on the significant non-ferrous alloys. The typical non-ferrous alloys taken into account for review are Aluminium alloy, Magnesium alloy and Copper alloy.

II. ALUMINIUM ALLOYS

1) K. E. Lulay, et. al. comprises the effect of the effects of deep cryogenic treatment on 7075 -T 651 Aluminium alloy. The treatment concluded of keeping the test specimen on a cryogenic cooler (-196◦C) for two different time span of 2 hours and 48 hours. The two different time span of 2 hours and48 hours are conducted to determine the existence of any independent effects and to evaluate the soaking effects respectively. The test specimen is then tested for its properties life proportionality limit, yield strength, ultimate tensile strength, hardness and elongation. As the result of all testing made on the specimen, there is no significant effects on the properties in 2hours treatment and slight increase in strength and toughness whereas a slight decrease in hardness in 4hours treatment.

2) Adam. L. Woodcraft determines the thermal conductivity of the Aluminium alloys between two different temperatures likely superconducting transition temperature (approximately 1K) and room temperature. The Aluminium alloys taken for account are Aluminium 6082 and 1000 series and the types 2014, 2024, 2219, 3003, 5052, 5083, 5086, 5154, 6061, 6063, 6082, 7039 and 7075. The testing was made between the temperature range between 1K and the room temperature.

Extrapolating the thermal conductivity from superconducting transition temperature measurements generally produced results by 10% or better values which agree with true measured values.

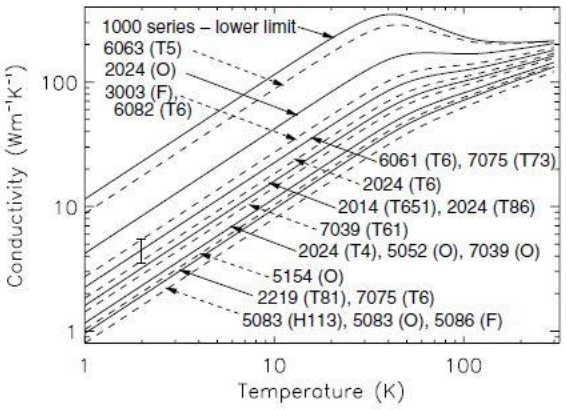

Fig. 1. Temperature Vs Conductivity

3) JI WANG.., et.al. This paper was to deal with the effects of low-temperature aging treatment at 120 ºC for 8 hours on the friction stir welded joints of 2024-T351 aluminium alloys with and without deep cryogenic pre- treatments. The specimen of 2024-T351 Aluminium alloy was subjected to a pre-treatment at 77K and notable changes occurred in the microstructure and mechanical properties during its investigation. The conduction of pretreatment results in the improvement of tensile strength and elongation. The low temperature aging treatment had not posses any significant changes in the various zones of the weld bead.

4) Joel Hemanth description of the testing of mechanical properties and tribological behavior of the composite Aluminium -12% Si alloy as matrix and Boron Carbide (B_4C) particles as reinforcement for synthesis of the composite, when it is subjected to cryogenic conditions (sub zero chilling). The mechanical properties that are considered for testing are ultimate tensile strength, hardness, wear resistance and strength. The tribological behavior the material (Al-B4C composite) is characterized using high rate heat transfer. As a result, the mechanical properties such as ultimate tensile strength, wear resistance and hardness are confirmed to be superior for chilled composites in comparison to the unchilled matrix alloy. Microstructures of the chilled composites with uniform distribution of B_4C (Boron Carbide) particles are finer than that of un-treated matrix alloy.

Elements	Zn	Mg	Si	Cu	Fe	Ni	Al	Mn
Composition (wt.%)	0.01	1.0	12.0	0.8	0.2	1.0	Bal	0.04

Fig. 2. Chemical composition of the Matrix Alloy

5) M. Araghchi proposed the methodologies to reduce the residual internal stresses during the quenching of Aluminium alloy (2024) which causes distortion followed by inessential effects on mechanical properties. The quenched samples were chilled by immersion in liquid Nitrogen of temperature -196°C and then it is allowed for reheating rapidly at 180°C by means of hot oil. The final investigation resulted in the reduction of residual stresses upto 71% comparatively higher than the traditional cryogenic treatment. (Usage of hot oil for uphill quenching rather than boiling water). In addition to that, the strength of Cryogenic treated sample was increased about 75MPa.

III. MAGNESIUM ALLOYS

6) E. Gariboldi et.al. proposed to verify the effects of deep cryogenic treatment on the high temperature behavior of the AZ91 Magnesium alloy. Comparative creep test were conducted at 100 and 200°C on high pressure die-cast specimens. The mechanical properties and micro structural stability were investigated by means of Optical and Scanning electron microscopy and Differential Scanning Caliometry (DSC) analysis. As a result, the microstructure remained similar on the specimens with and without Deep Cryogenic Treatment. Negotiable changes in the behavior were identified on the Mg alloys after heat treatment.

7) Liu Junwei et.al. investigated the effects of Cryogenic Treatment on AZ91 Mg alloy. The test specimens of AZ91 Mg alloys were subjected to Optical Microscope, XRD analysis, Resistance test and mechanical test to research the micro structure evolution and physical variation. The as-cast AZ91 Mg alloy specimens were allowed to an environment below 143K during heat treatment. The heat treated specimen resulted in the ordered structure of microstructure, improvement in peak stress, reduction in electric resistance and evolution of crystallographic lattice constant during analysis.

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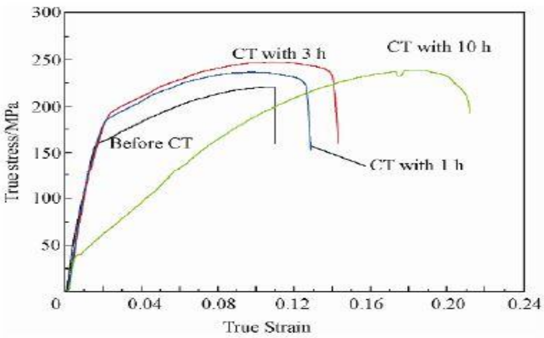

Fig. 3. True Strain Vs True Stress

Cryogenic time/h	Peak stress/MPa	True strain
0	215.4	0.11
1	239.7	0.13
3	248.9	0.14
5	246.3	0.18
10	240.3	0.21
24	253.2	0.23

Fig. 4. Average Mechanical Properties of the samples before and after Cryogenic Treatment

8) KAVEH MESHINCHI.., et.al. This paper is the description of the effect of deep cryogenic treatment on AZ31B alloy. The microstructure and mechanical properties of sub temperature treated -196° C specimen were investigated. The heat treatments were conducted on two phases likely cold treatment (CT) at the temperature range of up to -80° C and deep cryogenic treatment at about liquid- nitrogen temperatures up to -196° C.

Alloy code	% Al	% Zn	% Mn	% RE	% Mg
AZ91	9.10	0.90	0.25	-	Rem.

Fig. 5. Chemical Composition of the samples

Sample	Yield strength (MPa)	Ultimate tensile strength (MPa)	Hardness (BHN)
As-cast	91	170	59
After cryogenic	98	187	67

Fig. 6. Utimate Tensile Strength and Hardness of samples

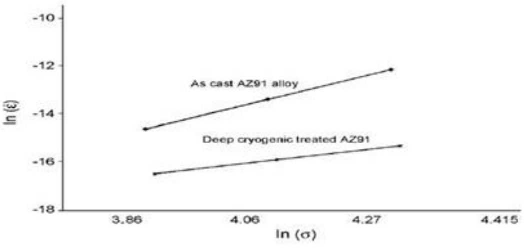

Fig. 7. Variation of Creep rates with stress for alloys tested at 200◦C

9) YANJIN SHEN.., et.al. This article was focused to sort out a newer process to remedy the problem of cracking between heat affected zone and fusion zone of a traditional laser welding. The magnesium alloy AZ91D was taken into account for laser welding. The newer process proposed was the method of laser welding of magnesium alloy AZ91D in assistance with a combination cryogenic and heat treatment. In the find analysis, the combination of cryogenic and heat treatment tended to obtain an increase in hardness and tensile strength of welded joint.

10) Hajo Dieringa.., et.al. This paper focused on the influence of cryogenic treatment on micro structure and mechanical properties of magnesium alloys. deep cryogenic treatment (DCT) at temperatures of 77K and below was mainly undergone for the proposed magnesium alloys. This caused the transformation of retained austenite into martensite structures. Various magnesium alloys were taken for investigation after cryogenic treatment like AZ91, AZ31, ZK60, MI5, MI10, MI12, VM12, IA91, IA141, and etc. on investigation of magnesium possessed higher values of ultimate tensile strength, yield strength, and lower percentage of elongation at liquid nitrogen temperature (i.e., 77K or -196° C). Even at very low temperatures there is no significant change in ductility.

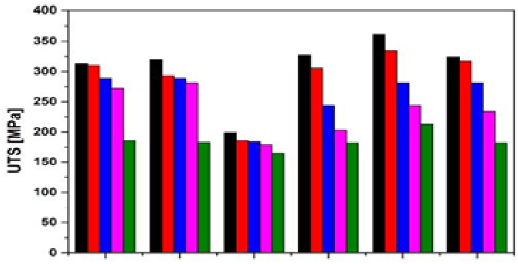

Fig. 8. Ulitmate Tensile Strength of cast magnesium alloys at 77, 194, 279, 366 and 422 K

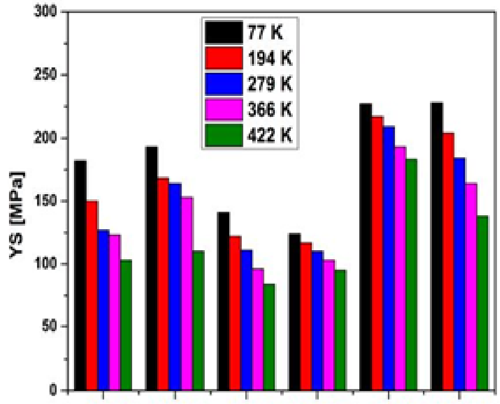

Fig. 9. Yield strength of cast magnesium alloys at 77, 194, 279, 366 and 422 K

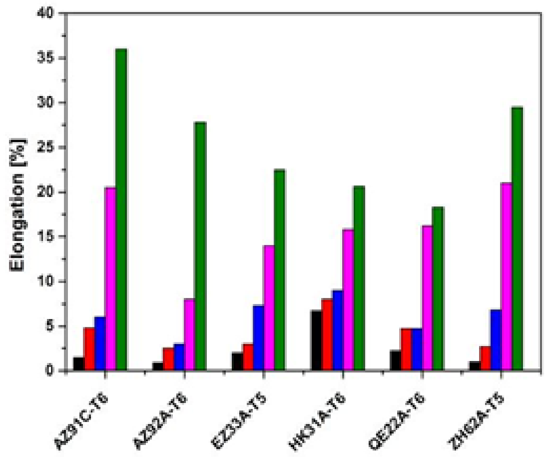

Fig. 10. Elongation of cast magnesium alloys at 77, 194, 279,366 and 422 K

IV. COPPER ALLOY

11) T. Shanmugasundaram.., et.al. In this article the effects of cryogenic rolling, low temperature annealing and ageing treatments on the precipitation hardening Al-cu (2219) alloy were reported. These experiments resulted in the negligible changes on the micro structure and mechanical properties of the Al-Cu (2219) alloy. The changes under optimal conditions were good ductility with 11% tensile elongation, improved tensile strength of up to 540 MPA and ultrafine grained microstructure.

12) Y.Yildiz. In this study, the effects of cold and cryogenic treatments in the machinability in EDM of Beryllium-Copper alloy were investigated. The test specimen (Beryllium - Copper alloy) was subjected to around -150ºF and -300ºF for cold and cryogenic treatments respectively, before machining by EDM process. The post machining results were about 20-30% increase in material removal rate, variations in wear rate, surface roughness and average white layer thickness were found to be marginal.

13) Wang ping., et.al. This paper discusses the investigation on the effect of cryogenic treatment on thermal physical properties on $Cu_{76.12}$ $Al_{23.88}$ alloy. The thermal physical properties like thermal diffusion co-efficient, heat capacity, thermal conductivity and thermal expansion co-efficient were measured on the $Cu_{76.12}$ $Al_{23.88}$ alloy before and after cryogenic treatment for comparative study. The comparative study showed that the thermal expansion co-efficient of $Cu_{76.12}$ $Al_{23.88}$ alloy increased largely with increasing temperature. The thermal diffusion co-efficient, thermal conductivity and thermal expansion co-efficient were supposed to increase and heat capacity could be reduced by cryogenic treatment.

14) X.B. Li.., et.al. This paper described the effects on micro structural behaviors and mechanical properties due to cryogenic rolling of pure copper sheets. In this investigation, fracture analysis, tensile tests and metallographic characterization were conducted after sub-zero temperature treatments. This ultra-low temperature activity led to the formation of nano scale mechanical twins and zigzag structures in the sheet center. It also resulted in the enhancement of yield strength and ultimate tensile strength.

15) Niraj Nayan.., et.al. In this article the mechanical properties were evaluated for the aluminum-lithium alloy AA2195 subjected to tensile testing under the condition of 7% cold working by the combination of stretching and cold rolling over a temperatures range from ambient to cryogenic conditions (liquid hydrogen -20K). This decrement in the temperature led to increase in tensile and yield strength, negligible changes in ductility and higher strength.

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VI. CONCLUSION

On conducting this review of various articles to research the effects of Cryogenic heat treatment on Non-Ferrous alloys, the following beneficial effects were obtained.

1. Cryogenic heat treatment enhanced the mechanical properties like yield strength, ultimate tensile strength and hardness on most of the non-ferrous alloys.
2. Although, negligible changes occurred in the microstructure of the cryogenically treated alloys which drastically reduced internal stresses and thereby increasing the percentage of Martensite structure.

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