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Effect of Soaking Time and Quenching Media on the Structure and Mechanical Properties of Al-5.6wt%Zn-2.5wt%Mg Alloy

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ABSTRACT

This research investigated the effect of soaking time and quenching media on the structure and mechanical properties of Al-5.6wt%Zn-2.5wt%Mg alloy. The samples were prepared using permanent die casting technique and machined to the required dimensions for the mechanical tests and structural analysis. The samples were solution heat treated at temperature of 300^{o}C for 30, 90 and 150 minutes and cooled in water, brine, palm oil and SAE40. Mechanical properties studied such as percentage elongation, ultimate tensile strength, hardness and impact strength were determined using 100KN JPL tensile strength tester (Model: 130812), dynamic hardness tester and impact testing machine (Model: U1820) respectively, while the alloy microstructures were studied using an optical metallurgical microscope (Model: L2003A) and scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS). The microstructural analysis revealed coarse micro-segregation of intermetallic compound ($MgZn_2$) in the control sample. The solution heat-treated samples revealed the presence of uniformly distributed fine grains of intermetallic compound ($MgZn_2$). The mechanical tests results showed that heat treatment improved the ultimate tensile strength, impact strength and percentage elongation of the alloy significantly. This was quantified by the presence of uniformly distributed fine grains of intermetallic compound ($MgZn_2$) in the alloy structure. Heat treatment created no room for solute redistribution of Mg and Zn and hence caused the elimination of micro-segregation of $MgZn_2$ in the alloy structure. Sample soaked for 30 minutes and quenched in water gave the maximum impact strength of 12J. The control sample had the maximum hardness value because of the presence of coarse intermetallic compound ($MgZn_2$) in the alloy structure.

Keywords: Soaking Time, Quenching Media, Structure, Mechanical Properties

I. INTRODUCTION

The development of aluminium alloys for automobile and automotive industries is of immense importance. It remains the main thrust of materials research and design for smaller and lighter components, to reduce fuel consumption and running costs. This is without prejudice to demand for quality such as high strength and ductility [1].

Aluminium-zinc-magnesium (Al-Zn-Mg) alloys are important alloys in engineering. They are mostly applicable in the aerospace and automotive industries. They present a wide range of potential applications due to their high specific mechanical properties [2]. Al-Zn-Mg alloys are heat treatable aluminium alloys that show characteristics like, decrease of the solid solubility as the temperature falls to room temperature and retention of high temperature single-phase solid solution by quenching to room temperature as supersaturated solid solution [2]. The strength of these alloys generally increases with the concentrations of zinc and magnesium. However, the alloys become prone to hot cracking during casting or during rapid cooling from a processing temperature, when the amount of Zn exceeds 7-8%.

It has been reported [3] that aluminium-zinc-magnesium (Al-5.6wt%Zn-2.5wt%Mg) alloy showed moderate strength and low ductility as a result of the

micro segregation of $MgZn_2$ precipitates which cause catastrophic failure of the alloy components. The effect of heat treatment on the structure and mechanical properties of squeezed Al-Zn-Mg alloy was studied [3]. The results of the study showed that the specimens aged at 120°C for 24 hours had the maximum hardness value. It was reported [4] that fast cooling rate for quenched sample produced fine grain and higher strength while slow cooling rates on annealed sample produced coarse grain and lower tensile strength. The study also showed that longer precipitation hardening time resulted to larger precipitates size that resulted to drop in strength (over ageing). A study [5] indicated that Al-Zn-Mg alloy heat-treated at 530^{o}C and quenched in water gave the highest hardness, tensile and yield strength of 35.50HRC, 109 N/mm^2 and 70.89 N/mm^2 respectively. Sample solution heat treated at 400^{o}C and quenched in sheanut oil gave the maximum impact strength. Study by [6] revealed that the tensile strength and ductility of aluminium alloy (Al-Zn-Mg) improved with changes in quenching rate. A study by [7] reported that an increase in quenching rate at and above 3°C/s resulted to a significant increase in hardness. The study also revealed an insignificant increase in hardness by increasing the solution treatment temperature. The study also revealed that quenching rate affected the amount of Si and Mg inside the dendrites for low quench rates. The study concluded that solution treatment temperature influenced the morphology of the intermetallic phases. Study by [8] reported that a maximum strength of 432.84MPa at temperature of 185^{o}C and ageing time of 6 hours. The study attributed it to the existence of small and round coherent precipitates dispersed throughout the alloy. Study by [9] reported that ultimate tensile strength increased with increase in soaking time from 6hrs to 20 hrs for treatment temperature of 90^{o}C. Maximum ultimate tensile strength of 198.8MPa and 188.6MPa were observed at 120^{o}C and 150^{o}C respectively at soaking time of 10hours. At 120^{o}C and 10hrs, the ultimate tensile strength was relatively the same as the as-received specimen, though with a higher fracture stress. The study also reported that annealing at 470oC resulted to lower ultimate tensile strength value of 114.3MPa and poor fracture resistance of 522MPa. These observations showed that solution treatment at 150oC for 10 hrs produced significant plastic flow before fracture of 6063 aluminium alloy. A study [10] revealed that the hardness of aluminium alloy increased with increase in ageing time, due to the enhanced presence of coherent Guinier-Preston (GP) zones in the aluminium matrix. It was reported that with further ageing (over-ageing), the hardness of the alloy decreased as the precipitate lost its coherency with the alloy matrix. Study [11] revealed that the addition of copper facilitated the growth of clusters (GP I) to the critical size during pre-ageing. The study indicated that addition of copper accelerated the transition from GP I (pre-β″) to GP II (β″) during final artificial ageing which finally resulted to the favourable paint-bake response. However, the one with the copper level of 0.3% did not show significant baking hardening response as expected. Study [12] reported that the hardness of 6082 alloy increased with increase in solutionizing temperature. The study attributed it to the amount of Mg and Si in a supersaturated solution, which contributed to the formation of the hardening particles of β-Mg_2Si phase precipitated during the ageing process. The number of GP zones and strengthening phases increased with increase in alloying content.

II. MATERIALS AND METHOD

Aluminium wire, magnesium and zinc powder served as the base materials for this research while water, brine, palm oil and SAE 40 served as the quenching media. The samples were cast using permanent die casting method. The required amount of pure aluminium wire was melted in a bailout crucible furnace and the predetermined amount of zinc and magnesium powder wrapped in an aluminium foil were added to the aluminium melt and stirred vigorously to ensure homogeneity. The mixture was poured into a preheated mould, machined to the required dimension for the mechanical tests and stored for the heat treatment process.

With the aid of a muffle heat treatment furnace, the machined specimens were heat treated at solutionizing temperature of 300^{o}C for 30, 90 and 150 minutes and cooled in water, brine, palm oil and SAE 40 and stored for the mechanical tests

III. Results and Discussion

Plates 1-14 and Figures 1-4 show the microstructure and mechanical properties of the studied alloy respectively.

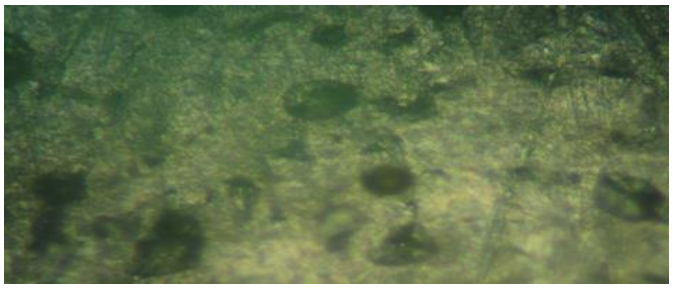


Plate 1: Micrograph of Al-5.6wt%Zn-2.5wt%Mg alloy (Control)

Plate 2: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 30minutes and cooled in water

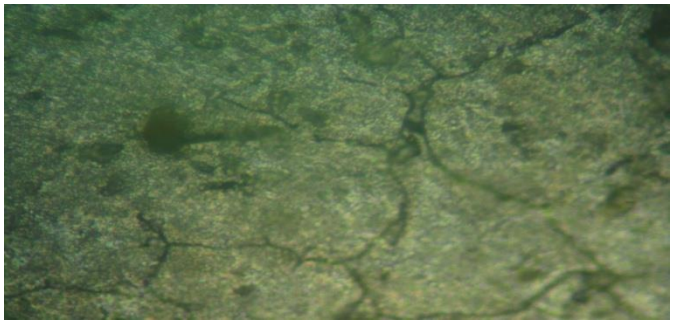


Plate 3: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 90minutes and cooled in water

Plate 4: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 150minutes and cooled in water

Plate 5: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 30minutes and cooled in brine

Plate 6: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 90minutes and cooled in brine

Plate 7: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 150minutes and cooled in brine

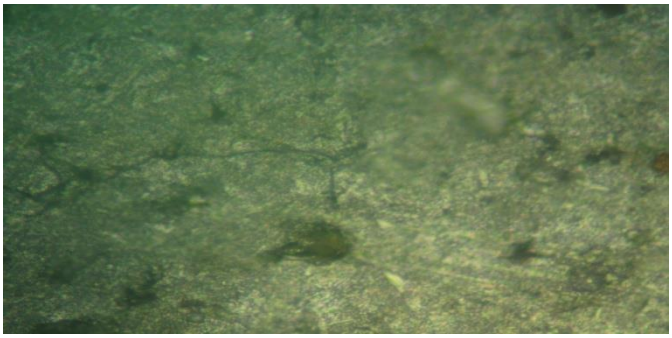


Plate 8: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 90minutes and cooled in palm oil

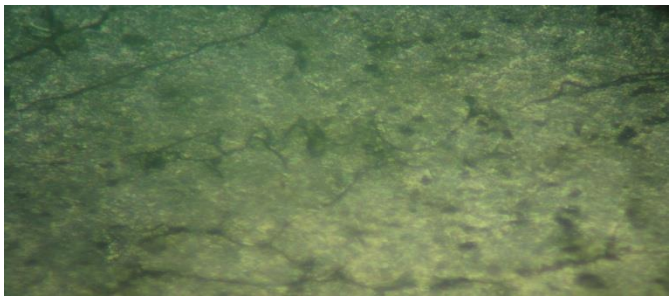


Plate 9: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 150minutes and cooled in palm oil

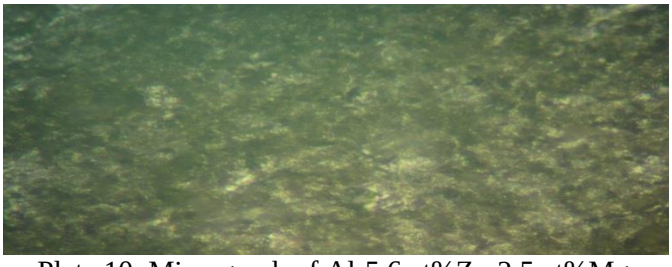
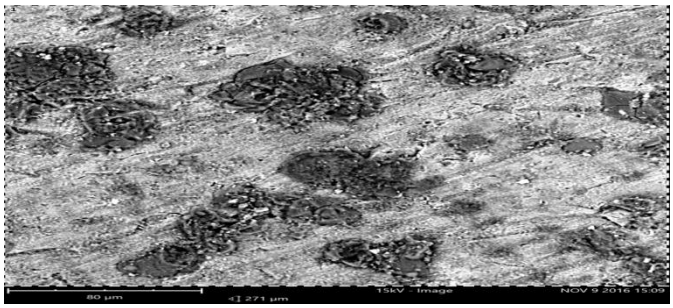


Plate 10: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 30minutes and cooled in SAE40

Plate 11: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 90minutes and cooled in SAE40

Plate 12: Micrograph of Al-5.6wt%Zn-2.5wt%Mg soaked for 150minutes and cooled in SAE40



Plates 13: Micrograph (SEM) of Al-5.6wt%Zn-2.5wt%Mg alloy (Control)

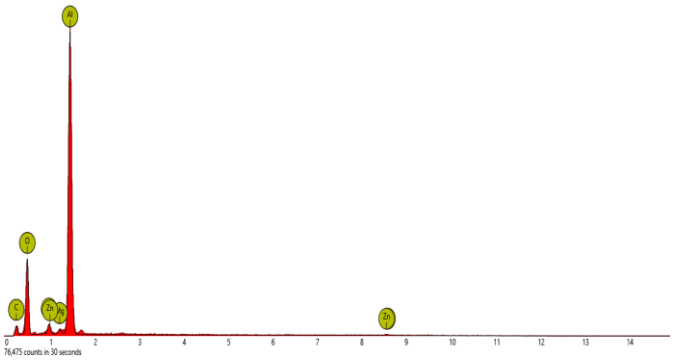
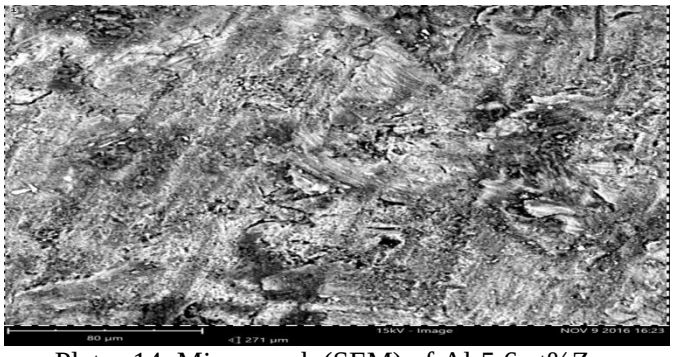


Figure 1: EDS spectrum of Al-5.6wt%Zn-2.5wt%Mg alloy



Plates 14: Micrograph (SEM) of Al-5.6wt%Zn-2.5wt%Mg alloy soaked for 30minutes and cooled in water

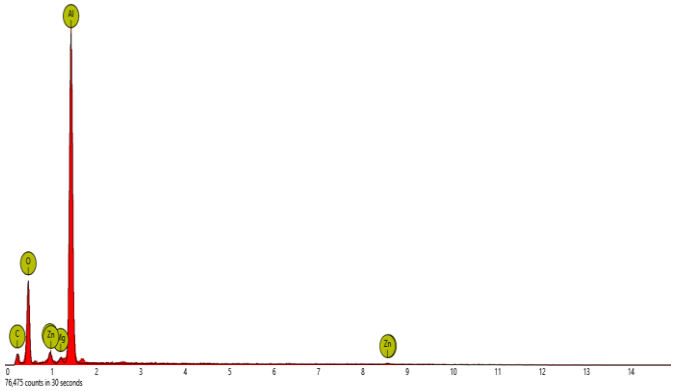


Figure 2: EDS spectrum of Al-5.6wt%Zn-2.5wt%Mg alloy

Plate 1 shows the micrograph of the control specimen (Al-5.6wt%Zn-2.5wt%Mg alloy). The microstructure consisted mainly of α-Al dendrites and micro-segregation of $MgZn_2$ in aluminium matrix. Plates 2-12 show the micrographs of the specimens, solution heat-treated at temperature of 300^{o}C for 30, 90 and 150minutes and cooled in water. Plates 2-4 revealed fine grains of intermetallic compound ($MgZn_2$) phase uniformly distributed in the aluminium matrix. There was no room for solute redistribution of Mg and Zn and hence no micro-segregation of $MgZn_2$ in the alloy structure. It was indicated in Plates 2-12 that the grains increased with increase in soaking time. During heat treatment, the micro-segregations formed after gradual cooling dissolved to form a homogeneous phase, which disappeared after subsequent cooling. Plates 5 and 6 show the micrographs of the specimens solution heat treated at temperature of 300^{o}C for 30, 90 and 150 minutes and quenched in brine. The micrographs showed coarse grains of $MgZn_2$ phase non-uniformly distributed in the aluminium matrix. It was revealed in Plates 5 and 6 that the size of the intermetallic compound increased with increase in soaking time. The micrographs revealed larger grains compared to the samples quenched in water. Plates 7-9 showed the micrographs of the specimens solutionized at temperatures of 300^{o}C for 30, 90 and 150 minutes and quenched in palm oil. The micrographs revealed fine needle-like intermetallic compound evenly distributed in aluminium matrix. Plates 7-9 revealed larger grains, which increased with increase in soaking time. Plates 10-12 showed the micrographs of the specimens solutionized at temperatures of 300^{o}C for 30, 90 and 150 minutes and quenched in SAE40. The micrographs revealed very fine grains evenly distributed in the aluminium matrix (Plates 10-12). It was evidenced in Plates 10-12 that the size of the grains of intermetallic compounds reduced with increase in soaking time. The

scanning electron microscopy analysis of the control specimen presented in Plate 13 revealed micro segregation of $MgZn_2$ intermetallic compound randomly distributed in the aluminium matrix. Plate 14 revealed that the micro-segregated intermetallic compound dissolved to form a homogeneous phase and fine grains of intermetallic compound ($MgZn_2$) phase uniformly distributed in the aluminium matrix when compared to the micrograph of the control specimen. Figures 1-2 present the elemental analysis (EDS) of the non heat-treated (control) and heat-treated samples of Al-5.6wt%Zn-2.5wt%Mg alloy. Figures 1-5 indicated the presence of five major elements, which include Al, Zn, Mg and O etc.

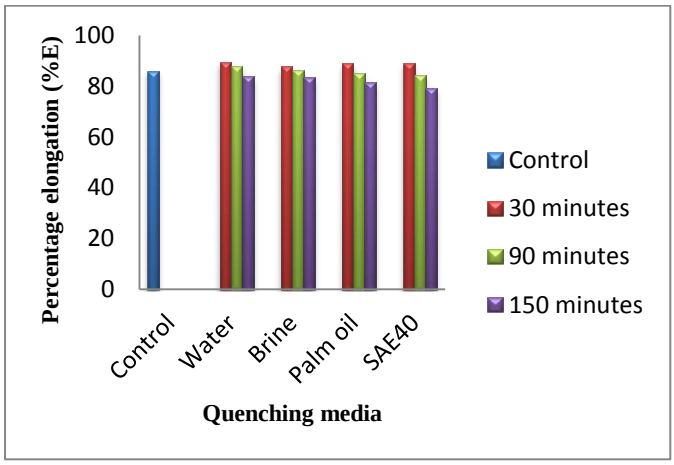


Figure 3: Effect of quenching media on the percentage elongation of Al-5.6wt%Zn-2.5wt%Mg alloy soaked for 30, 90 and 150 minutes.

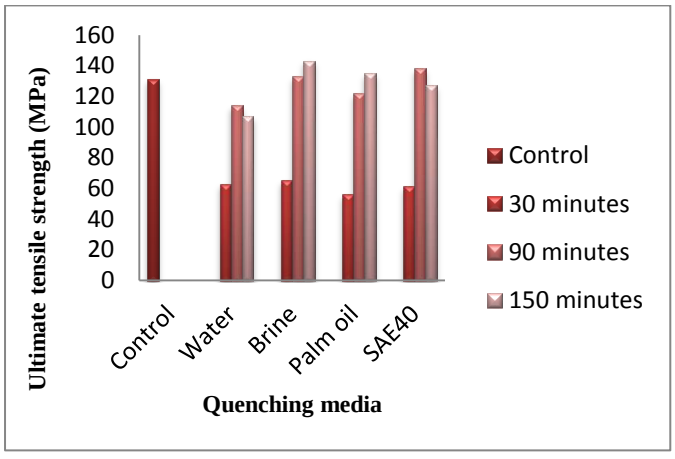


Figure 4: Effect of quenching media on the ultimate tensile strength of Al-5.6wt%Zn-2.5wt%Mg alloy soaked for 30, 90 and 150 minutes.

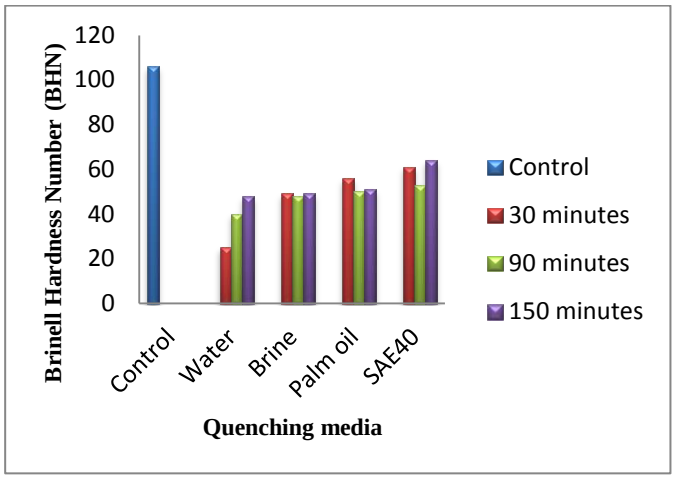


Figure 5: Effect of quenching media on the hardness of Al-5.6wt%Zn-2.5wt%Mg alloy soaked for 30, 90 and 150 minutes.

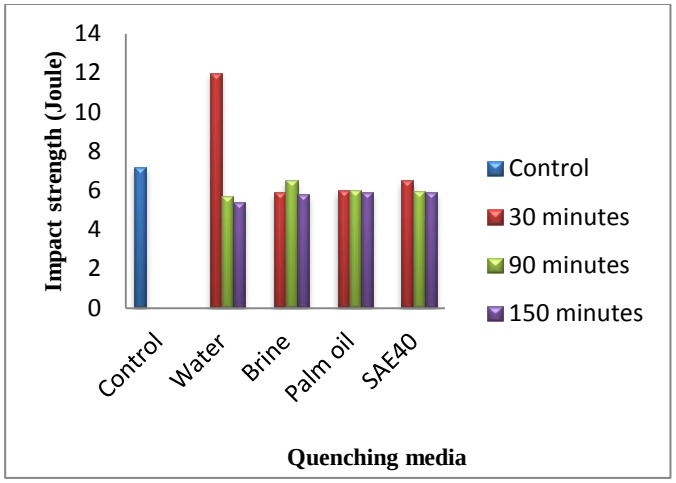


Figure 6: Effect of quenching media on the impact strength of Al-5.6wt%Zn-2.5wt%Mg alloy soaked for 30, 90 and 150 minutes.

Figures 3-6 show the effect of soaking time and quenching media on the percentage elongation, ultimate tensile strength, hardness and impact strength of Al-5.6wt%Zn-2.5wt%Mg alloy solutionized at temperature of 300°C. It was evidenced in Figure 1 that heat treatment significantly improved the percentage elongation of the studied alloy. Figure 3 indicated that the percentage elongation decreased with increase in soaking time. Figure 4 indicated an improvement in ultimate tensile strength of Al-5.6wt%Zn-2.5wt%Mg alloy soaked for 90 and 150 minutes and cooled in brine, palm oil and SAE40 respectively. It was noted in Figure 4 that the percentage elongation of the specimens quenched in brine and palm oil increased with increase in soaking time. The percentage elongation of the specimens quenched in water and SAE40 increased when the soaking time increased to 90 minutes and decreased with further increase in soaking time (Figure

4). It was evidenced in Figure 5 that heat treatment has negative impact on the hardness of Al-5.6wt%Zn-2.5wt%Mg alloy. Figure 5 indicated that the hardness value of the non-heat treated alloy (control) was higher than all the heat-treated samples. Figure 6 showed that the impact strength of the alloy studied improved significantly when soaked for 30 minutes and cooled in water.

IV. CONCLUSION

The effect of soaking time and quenching media on the structure and mechanical properties of Al-5.6wt%Zn-2.5wt%Mg alloy has been investigated using standard test technique. From the results, the following conclusions were drawn:

1. Rapid solidification process and heat treatment eliminated the formation of micro-segregation, and significantly improved the percentage elongation, ultimate tensile strength and impact strength of the alloy.
2. The mechanical properties of Al-5.6wt%Zn-2.5wt%Mg alloy were sensitive to their microstructural features such as the form, size and number of intermetallic compounds formed in the alloy structure.
3. Finer primary α- phase resulted to an increased tensile strength of the alloy while coarse primary α grains reduced the strength and ductility significantly despite identical hardness value.
4. Sample cooled in water after undergoing solution heat treatment at temperature of 300^{o}C and soaking time of 30 minutes gave the maximum impact strength of 12 joules.
5. The improved mechanical properties observed in the heat-treated samples were attributed to structural homogenization of the alloy structure.
6. The increased hardness value of the control sample was as a result of the presence of coarse intermetallic compound ($MgZn_2$) in the alloy structure.
7. The reason for the observed trend in hardness, percentage elongation, ultimate tensile strength and impact strength in the heat-treated samples was due to the variations in the grain size.
8. The maximum percentage elongation and impact strength observed in the alloy was quantified by the increased amount of soft α- phase present in the alloy structure.

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