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Influence of Solution Heat Treatment on Tensile Properties of Zinc-aluminum (ZA5) Solder Alloy

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Abstract

Zinc-Aluminum (ZA) alloys are important industrial alloys which are gaining widespread use for many industrial applications due to their excellent castability and cutting machinability. Since they were introduced in the early 1970s, various investigations have been carried out on this family of engineering materials to broaden the scope of areas where they can be usefully applied. While many investigations have been carried out on many of the ZA alloy materials, only few studies have reported investigations on ZA5. Therefore, this study investigated tensile properties of ZA5 alloy. Tensile strength, Fracture energy and Elongation properties of ZA5 solution heat treated were investigated. ZA5 alloy material was prepared in the laboratory and cast into rods of 15 mm diameter and 200 mm long. A sample of the cast rods was solution heat treated at 100ºC for 6 hours, while another untreated sample which served as control was equally produced. Tensile characteristics of the specimens were evaluated on Universal testing machine. Results showed that ZA5 alloy material exhibits superplastic behavior at low flow stress. Solution heat treatment performed on the alloy significantly modified the structure of the alloy, and increased the tensile strength of the alloy. By solution heat treatment at 100ºC for 6 hours, the tensile strength of the ZA5 alloy can be improved. In general, solution heat treatment of ZA5 alloy for 6 hours at 100ºC influenced the tensile properties of the alloy material.

Keywords: Solutionized; tensile strength; fracture energy; elongation.

1.0 Introduction

Soldering is one of the important engineering processes that have widespread application particularly in the electronics industry [1]. The process involves joining of two or more metals by melting and flow of a filler material referred to as solder, into the joint. Unlike in the welding procedure, where good mutual solubility of the base metals and the filler material is required, for soldering, melting of the base metal is not required. The success of soldered joint created depends largely on the type and properties of the solder-filler material used. The Tin-Lead eutectic alloy with 63% tin and 37% lead (or 60/40) has been the popular solder alloy of choice in many nations of the world. However, due to reasons of environment, and enactment of acts such as the European RoHS (Restriction of Hazardous Substances Directive), solder filler materials that do not contain lead or drastically reduced lead content are now recommended and are becoming more widely used. Because of this reason, research efforts are now being made to develop other solder filler materials that can replace the leaded solders. Some of the research efforts focused on developing new solder filler materials include various research efforts geared towards development of SnZn alloy systems. These include investigation of roles of heat treatment parameters on the mechanical properties of SnZn4.5; SnZn9; SnZn13.5; SnZnCu and SnZnAg [2]. The study reported that grains of eutectic with structures that are fine and fibrous with negligible amount of small acicular Zn-rich precipitates are beneficial micro-structure, which is the cause of high mechanical properties of SnZn9 alloy produced by casting. Majority of literature on solder materials had the focus on understanding micro-structures, mechanical properties and relationship of microstructures and mechanical properties [3-6]. Similar work on solder materials was the study on ease of wetting and strength of bonds of solder joint couples by Sobesak et al. [7]. Other solder filler materials that were used include: Tin-Zinc for joining Aluminum, Lead-Silver for strength at higher than room temperature, Cadmium-Silver for strength at high temperatures, Tin-Silver; Tin-Bismuth for electronics; and Zinc-Aluminum (ZA) solder alloys for joining Aluminum and for corrosion resistance. Zinc-Aluminum solder alloys are particularly good because these are the only solder filler materials containing Zinc as the major element, where anti-sparking property can be exploited in electrical appliances. In ZA solder filler materials, Zinc and Aluminum are the significant alloy elements, together with other insignificant additions of magnesium and copper. The numbers associated with the name indicate the amount of weight percent of Aluminum in the alloy (i.e. ZA8 has 8% Aluminum by weight).

Since the family of ZA alloys was introduced in the early 1970s, various investigations were carried out on this family of engineering materials to broaden the scope of areas where they could be usefully applied. Particularly, research efforts were made to understand the phenomenon of dendritic segregation in these alloys [8]; effects of casting / processing techniques of structural formations in the ZA alloy [9-11]. Efforts were also made to investigate their mechanical properties [9, 12-13], however, mostly, tensile properties of the high Aluminum content ZA alloys types were more studied. Only few studies have reported research efforts on ZA5, one of the important materials in this family of alloy useful for soldering application. No research efforts reported investigations on heat treatment effects on ZA5 alloy. To meet the increasing demand for industrial application of these alloys, many investigations on changes in microstructure and transformations happening in the phases, which occur during various thermal and thermo-mechanical processes, are required [14]. Generally, understanding mechanical properties of materials is very important [15-18] to provide knowledge which is very useful and significant for design and many other important engineering adaptations.

Therefore, in this work, investigation into tensile properties of ZA5 was made. The influence of solution heat treatment at 100ºC for 6 hours on the tensile strength, maximum extension, maximum strain, and fracture energy values of the alloy was investigated.

2.0 Materials and Experimental Procedure

The material used for the study is Zinc-Aluminum alloy (ZA5). This material was produced by melting together and casting zinc and aluminum metals. About 9kg of Zinc metal scrap was melted in a lift-out crucible furnace, after which about 0.5kg of Aluminum was dissolved in the molten zinc metal. The molten metal alloy mixture produced was cast into rods of 15mm diameter and 200mm length in sand molds. The quantitative elemental chemical analysis of the cast rods was carried out with optical emission spectrometer. Chemical analysis test result is presented in **Table 1**. Produced cast rods were machined into ASTM standard tensile test pieces on a lathe for tensile testing on the Universal Testing Machine. Two test pieces were produced from the cast rods. One test piece served as control specimen, while the other test piece was heat treated at a temperature of 100ºC for 6 hours, after which the sample was removed and quickly quenched in water maintained at a temperature of 10ºC. The treated test piece had length of 51.2 mm and diameter of 5.1 mm while the control sample had length of 29 mm and diameter of 4.77 mm. Both test pieces were then evaluated for tensile properties on Universal Testing Machine. The results from the Universal Testing Machine produced the tensile strength, maximum extension, maximum strain, and fracture energy values of the tested samples. The stress-strain plots of the tested samples were also produced by the Universal Testing Machine, and these plots were obtained for further analysis.

3.0 Results and Discussion

Table 1, Table 2 and **Fig. 1-4** are the results obtained from this work. **Table 1** presents the results of the elemental chemical analysis of the produced ZA5 alloy. **Table 2** shows the results of the tensile properties of the samples as tested by the Universal Testing Machine. **Fig. 1** through **Fig. 3** show the stress-strain curves for the untreated (control) and the solutionized samples respectively. The microstructures of the control and the treated samples are presented in **Fig.2-4** respectively.

Table 1 : Chemical composition of the ZA5 alloy

	Mn	Si	Cu	P	Cr	Ni	V	B	Al	Mg
Mean (Conc. %)	0.13	0.12	1.47	<0.0005	0.005	0.12	0.002	0.0135	15.4104	0.0005
	Ca	Ti	Zr	Fe	Ag	Zn	Sn	Pb	Co	Na
Mean (Conc. %)	0.0003	0.003	0.001	0.036	0.035	>79.0	0.002	3.74	0.004	<0.0001

Table 2 : Tensile properties of the tested samples of ZA5 alloy

Sample	Tensile strength (MPa)	Fracture energy (Joules)	Maximum extension (mm)	Maximum tensile (mm/mm)
Solution treated ZA5	210	1.24	0.89156	0.01741
Untreated ZA5	190	0.56	0.71669	0.02471

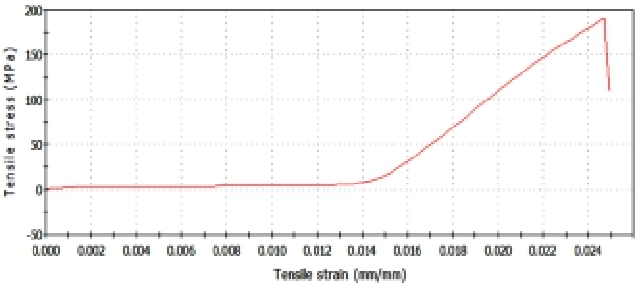

Fig. 1 : Stress-Strain curve for control sample

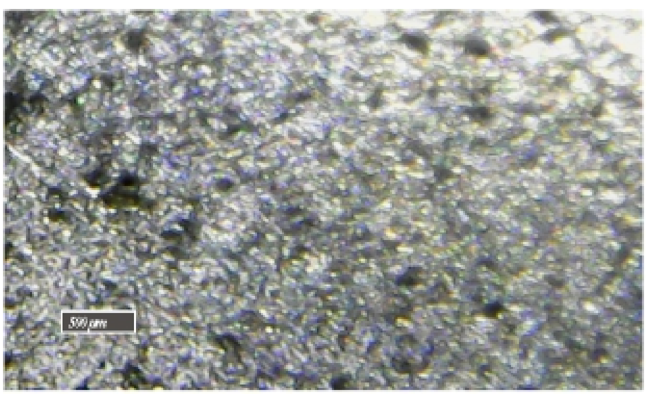

Fig. 2 : Microstructure of control sample

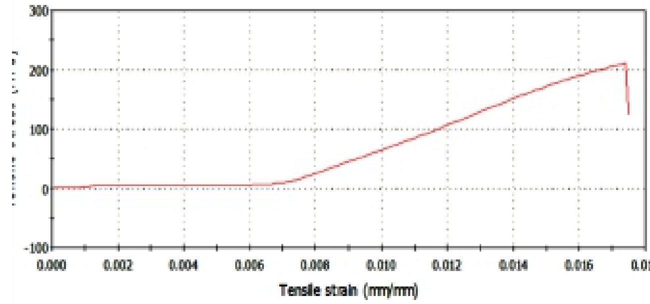

Fig. 3 : Stress-Strain curve for solutionized sample

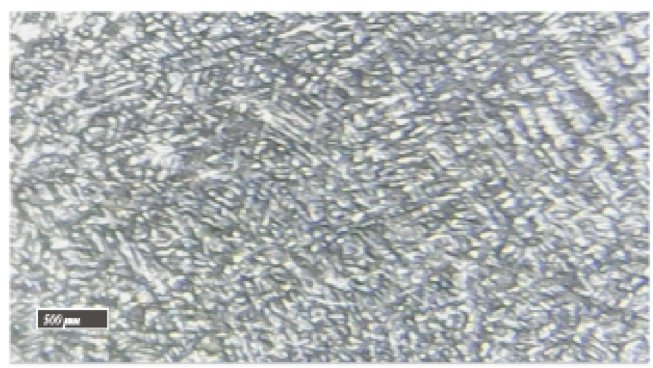

Fig. 4 : Microstructure of solutionized sample

Results of elemental chemical analysis, as given in **Table 1,** show that Zn (79 Conc. %) and Al (15 Conc. %) are the significant elements in the ZA5 solder alloy with quite low percentages of Pb (3 Conc. wt%). **Table 2, Fig. 1** and **Fig. 3** present tensile strength, fracture energy, maximum extension, and maximum strain values of the tested samples as measured by the Universal Testing Machine.

The results show that the untreated (control) sample had tensile strength of 190 MPa, while the solution heat treated sample has a higher tensile strength value of 210 MPa. The stress-strain curves show a tensile behaviour where low flow stresses produce large extensions. Overall, about 61% of the whole deformation is induced by low flow stresses as shown in **Fig. 1**. Similarly, the lower part of **Fig. 3** shows that quite large extension by low applied stresses is until 0.007 mm/mm tensile strain from which the material gets stiffer until fracture at 0.0175mm/mm tensile strain. At this fracture point, only about 40% of the total deformation is induced by low applied stresses.

Results of the fracture energy evaluation show that the control sample has fracture energy of 0.56 J while the solution heat treated sample has higher energy value of 1.24 J. Control sample has maximum extension of 0.717 mm which translates to 2.5 % elongation, while the solution heat treated sample has a maximum extension of 0.892 mm which translates to 1.7% elongation.

The energy values are rather low and indicative of the concave-up (J-type) stress strain curve [15, 16] observed for the samples (**Fig.2** and **Fig.4**). J-type stress-strain curves normally exhibit low area under the stress strain plot, indicating low energy absorption during the deformation of samples by tensile tests [16]. Materials exhibiting J-shaped stress-strain curves can be extremely tough, even if their fracture energy for the same material is not particularly high [16]. This toughness arises for the fact that lower part of the J-shaped curve shows large elongations for low applied stress, so the shear modulus in this region is quite low, and so, there is no mechanism whereby the released strain energy on fracture can be transmitted to the fracture zone. Areas of large extensions for low applied stresses are seen in **Fig. 1** and **Fig. 2**. The material gets stiffer as it approaches failure point ensuring that large elongations need large stresses. Because the J-shaped curve is concave-up, the area under the curve up to a given elongation is much lower than for equivalent Hookean curve, meaning that the energy released in the fracture of a material with a J-shaped stress-strain curve is much less than the energy released when equivalent Hookean material fails. Because the release of energy drives crack propagation, a material that releases less energy on fracture is tougher [16].

The improved fracture energy values of the solutionized specimen can be due to the fine and stable grain size of the aluminum-rich (α-phase) and zinc-rich (β-phase) terminal solid solutions superplastic microstructure formed during solution treatment of the alloy at 100ºC [11]. Superplastic states have been reported to improve strength [9, 11]. The presence of superplastic structure is confirmed in the micrograph of solution heat treated sample presented in Fig. 4.

4.0 Conclusion

Results of the investigation show that ZA5 alloy solution heat treated has improved tensile strength. The fracture energy values for both treated and untreated samples are rather low. This alloy in the as cast and solution heat treated states exhibits superplastic condition, where low flow stresses brings about high elongation in the material. By Solution heat treatment at 100ºC for 6 hours, the tensile strength of the ZA5 alloy can be improved. This suggests that the tensile strength of joints soldered with ZA5 will improve with use due to in-advertent heating by current flow through the soldered joint. In general, solution heat treatment of ZA5 alloy for 6 hours at 100C influenced the properties of the alloy material.

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