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Study of Mechanical Properties of Zn-27Al Alloy Cast in Metal Mould at Different Casting Conditions

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Abstract— **In the last forty years a series of zinc-aluminum alloys, termed "ZA" alloys have been developed to compete with well known alloys such as brasses, bronzes and cast irons. The ZA alloys are well suited to applications requiring high cast strength, hardness and wear resistance. The alloy ZA-27 looks particularly attractive. It can be used for the manufacture by gravity sand casting and permanent mould casting of complex parts characterized by tensile strength well over 400Mpa. The aim of this study is to produce commercially available ZA-27 alloy cast in metal mould and to study its mechanical properties at different casting conditions. A cast iron metal mould was prepared and ZA-27 alloy was cast at different conditions. The casting variables were pouring temperatures of the melt. Casting was conducted at pouring temperatures 650°C, 700°C and 750°C where the mould preheat temperature was fixed at 300°C. To determine the mechanical properties tensile and hardness test were performed. The best combination of mechanical properties for the alloy ZA-27 cast in metal mould was obtained at melt pouring temperature 700°C.**

Index Terms— **Casting, metal, mould, ZA-27 alloy, hardness, tensile strength, pouring temperature, preheat temperature, percentage elongation, ductility**

I. INTRODUCTION

Hypoeutectic zinc-aluminum alloys have been used since the year 1930. These alloys are based on the hypoeutectic Zn-4Al composition. These alloys are primarily used for die casting applications due to their superior properties. They display excellent cast ability, easy finishing, are economical and possess good mechanical strength [1]. With such properties they are used for a wide range of decorative and light structural parts and lend themselves readily to rapid mass production techniques. These factors account for their widespread use in the automotive industry. The range of zinc-aluminum alloys was expanded in the last fifty years by the introduction of a series of hypereutectic zinc-aluminum alloys [2].

These hypereutectic alloys are commonly referred to as foundry or "ZA (for Zinc-Aluminum) alloys". In the year 1962, the International Lead Zinc Research Organization (ILZRO) introduced IIZRO 12(since referred to as ZA-12) containing 11%Al-0.75%Cu-0.02%Mg. In the late 1970s, the Noranda Research Centre developed two additional alloys, ZA-8 and ZA-27 (the '8' and '27' refer to the approximate weight percent of aluminum). The alloys were developed to compete with other mature alloy systems, such as brasses, bronzes, aluminum based alloys and cast irons [3].

The ZA alloys are suitable for casting by a variety of methods including permanent mould and high-pressure die casting. Advantages are often associated with the use of the ZA alloys include high mechanical properties, low melting energy consumption, machinability, and excellent bearing characteristics and wear resistance [4].

Zn-Al system offers the advantage of unlimited solubility, without its leading to the formation of deleterious intermetallic compounds. Depending on the aluminum content under consideration, the freezing range can however, vary substantially, and the as cast microstructure can exhibit very distinct features. All the Zn-Al alloys now commercially available are strengthened by copper and magnesium additions. The former induces the occurrence of supplementary phase which do not derive from the binary equilibrium diagram. In this connection it must be pointed out that, on top of its hardening and unfortunately enough embrittling effect, Mg helps increase the resistance to intergranular corrosion. On the other hand, cu improves creep and corrosion behaviors [5].

The economic benefits and inherent properties of ZA alloys account for their use in a rapidly growing list of industrial applications, including: industrial fittings and hardware, pressure tight housings, sleeve bearings, thrust washers, wear plates, electrical switchgear and hardware, hose couplings and connectors, fire fighting hardware, pneumatic and hydraulic cylinder components, pulleys and sheaves, non-sparking mining hardware, decorative hardware etc [6].

One of these alloys is particularly attractive, as it combines very high strength (typically well over 400 MPa) and moderate density. It was developed by NORDANA under the trade name of ZA-27, which is meant to indicate that it contains about 27%Al (Zn-27Al-2Cu-0.015Mg) [7].

The strength of the zinc-aluminum alloy increases with the aluminum content, so that the 27% aluminum alloys have a high tensile strength. The Zn-Al system has a eutectic at approximately 5% aluminum, so that in the commercial alloys the temperature range over which freezing occurs also increases as the aluminum content increases until in the case of 27% aluminum alloy, the freezing range is nearly 109°C. Its freezing range is wide particularly in comparison with its low liquidus temperature [8]. This naturally makes it prone to solidification micro shrinkage, and then casting conditions must then be chosen carefully, in order to secure the internal soundness [9].

The aim of this study is to produce commercially available ZA-27 alloy cast in metal mould at different casting conditions and to compare its properties with those of aluminum and copper base alloys. Considering the importance of suitable foundry alloys, it is necessary to understand the production process of zinc aluminum foundry alloy and the metallurgy behind in optimize various

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parameters to produce sound casting. It is also necessary to verify its suitability as foundry alloy compared to other alloys. In this project permanent metal mould was used which has various advantages. There is no need to make the mould again. It is less time consuming. It is cost effective in terms of mass production. The alloy is so chosen that ZA-27 is about 17% lighter than ZA-11 and 21% lighter than ZA-8. The electrical conductivity is higher than ZA-11 and ZA-8. The ductility of ZA-27 is higher than these two alloys. ZA-27 is significantly more creep resistant [10]. ZA-27 alloy can be recommended for stress application up to 150°C. As permanent mould is used here smooth surface finish of the cast is desirable. It requires less material than sand casting and also eliminates the operation of machining and grinding.

II. Experimental procedure

A. Mould making

Cast iron was chosen for mould making. The mould block was sand cast and grinding was done. Extra feeder part was removed by hacksaw from the proposed block.

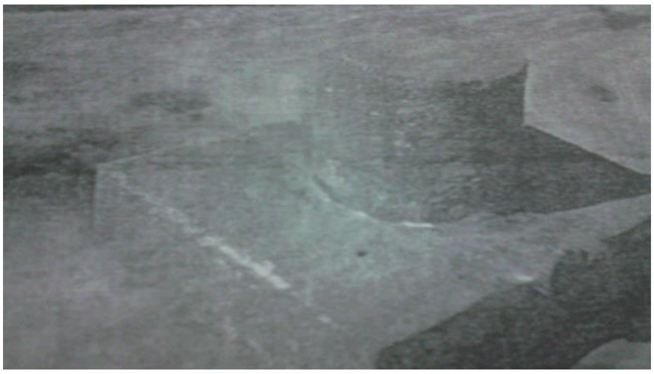

Fig. 1. Sand cast block of cast iron with feeder

After sand casting the blocks were given proper dimension by machining. Then two cope parts were joined together with screws. Sprue cavity and specimen cavities were made by thorough drilling.
The drag part was machined to obtain the runner and sprue base cavity. In this case milling was done by the milling machine and the material was removed from the block forming the desired shape.

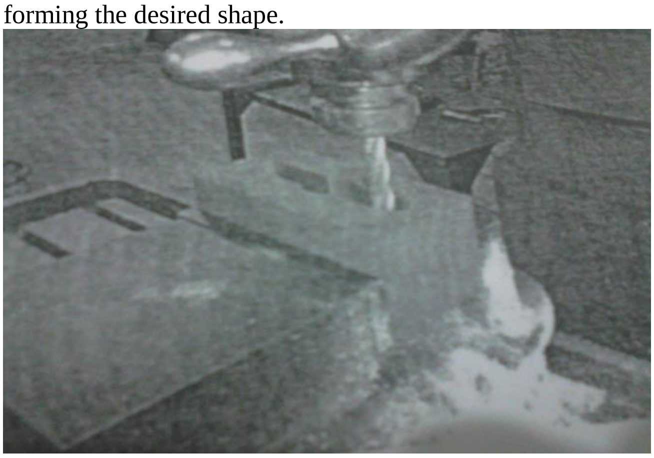

Fig. 2. Milling the drag part of the mould

B. Casting Condition

Mould used: Permanent mould of cast iron
Alloy used: ZA-27

Additives used: Copper 1% and Magnesium 0.02%
Casting variables: Pouring Temperature
Preheat temperature of the mould: 300°C
Pouring temperatures of the melt:

1. 650°C
2. 700°C
3. 750°C

C. Melt Practice

Experimental zinc-aluminum alloys were prepared using special high grade zinc (99.99% min), commercial purity aluminum (99.95%min), electrolytic tough pitch copper (99.99%min), and commercial purity magnesium (99.8% min). In this experiment the alloy was melted in a pit furnace. Since aluminum does not dissolve readily in molten zinc, the aluminum was melted first, along with any copper addition. Zinc was added to aluminum and magnesium was preferably introduced just before casting.

The alloyed bath was stirred vigorously to ensure batch homogeneity and allowed to rest prior to skimming. The alloy was transferred to the mould using suitable ladles and pouring was done to prevent skimming from being entrained. The experimental alloy was cast in to standard test pieces using well established casting patterns.

Before preheating the mould, a coating was applied in to the mould. In this experiment calcium carbonate was used as a coating material. After coating the mould was used with a gas flame. The mould was heated as it got uniform temperature over the entire mould. To obtain the desired preheat temperature the surface temperature were measured at various locations and average temperature was taken as the preheat temperature.

The ladle was removed from the furnace and melt temperature was measured with a thermocouple. When the melt temperature reached to the desired pouring temperature the melt was poured into the mould. The pouring was done carefully so that mould cavity was filled with the liquid metal. Then the casting was allowed to cool. Then the solidified casting was removed from the mould.

III. Determination of properties

The samples of all the three casting conditions were subjected to hardness and tensile test. The %elongation was also measured. All the results of hardness test and tensile test were tabulated in Table1, Table2, and Table3.

D. Hardness Test

The hardness of the samples was measured by using Brinnel hardness testing machine. The indentations were made on the specimens using 100kg load for 30 seconds.

Table 1: Measured Hardness of all samples cast at different pouring temperature

Pouring Temperature(°C)	Sample No.	Hardness (HRB)	Average Hardness (HRB)
650	1	40.3	38
	2	42.3	
	3	48.9	
	4	38.2	
	5	32.5	
	6	25.8	
700	1	41.2	43.33
	2	43.8	
	3	42.9	
	4	43.8	
	5	42.5	
	6	45.8	
750	1	49.9	49.35
	2	45.6	
	3	53.6	
	4	50.2	
	5	42.5	
	6	54.3	

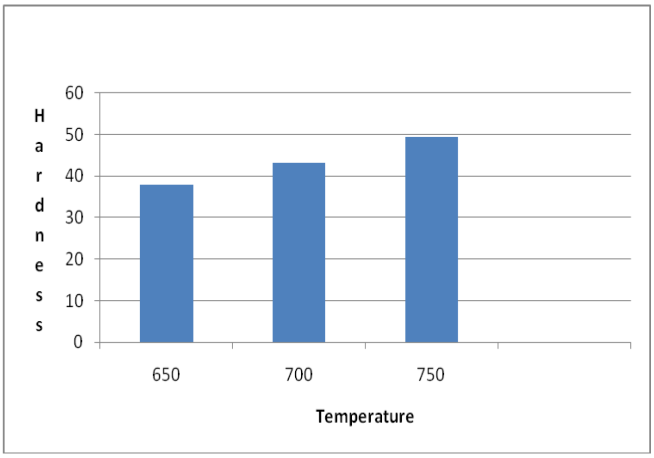

Fig. 3. Hardness of ZA-27 alloy cast at different pouring temperature

From Fig.3 as the pouring temperature increases the hardness of ZA-27 alloy increases. From Table1 maximum hardness 54.3 was obtained with the specimen cast at pouring temperature 750°C.

E. Tensile test

Tensile strength and ductility of the samples were measured by using a Universal Testing Machine and have been tabulated in Table2 and Table3.

Table 2: Measured Tensile Strength of all samples cast at different pouring temperature

Pouring Temperature(°C)	Sample No.	UTS (MPa)	Average UTS (MPa)
650	1	266.3	258.8
	2	258.8	
	3	258.3	
	4	260.3	
	5	253.2	
	6	255.8	
700	1	292.2	296.5
	2	299.8	
	3	297.9	
	4	296.8	
	5	293.5	
	6	298.8	
750	1	259.9	257.7
	2	263.6	
	3	259.6	
	4	248.2	
	5	254.5	
	6	260.3	

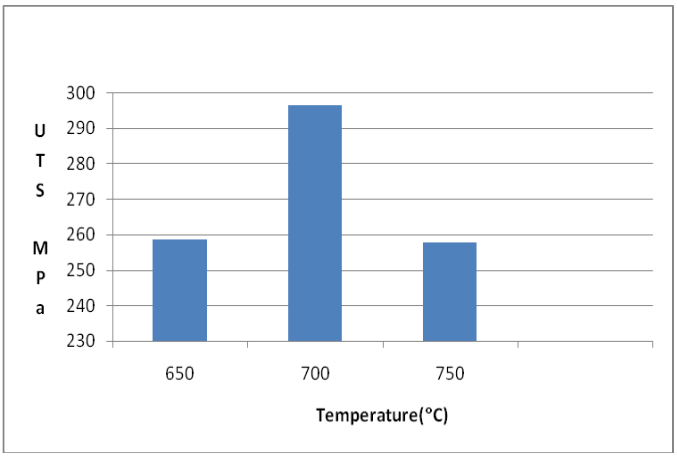

Fig. 4. Tensile strength of ZA-27 alloy cast at different pouring temperature

Fig.4 shows as pouring temperature increases UTS increases. Then further increase in pouring temperature causes decrease in UTS. From Table2 maximum tensile strength 299.8 MPa was obtained with the specimen cast at pouring temperature 700°C.

Table 3: Measured %elongation of ZA-27 alloy cast at different pouring temperature

Pouring Temperature(°C)	Sample No.	Elongation mm	Average % elongation
650	1	0.0	0.1
	2	0.1	
700	1	1.0	1.7
	2	0.7	
750	1	0.3	1.2
	2	0.9	

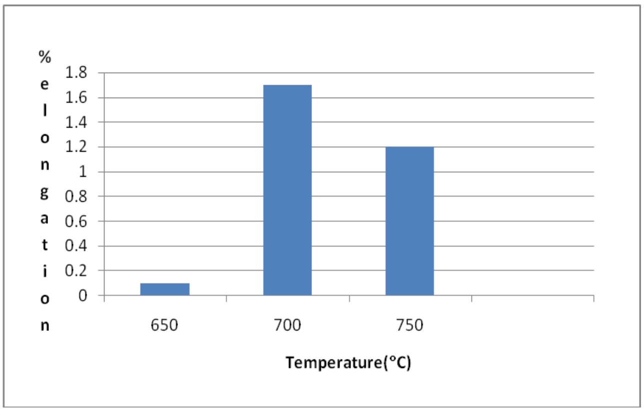

Fig. 5. %elongation of ZA-27 alloy cast at different pouring temperature

Fig.5 states that as pouring temperature increases percentage elongation increases. Then further increase in pouring temperature decreases % elongation. Maximum ductility was observed with the specimen cast at pouring temperature 700°C.

IV. Conclusion

From the present experiment the following conclusions can be drawn

- As pouring temperature increases tensile strength increases but above 700°C the tensile strength decreases. As pouring temperature increases grain size become smaller which strengthen the structure and a higher tensile strength can be achieved. But at higher temperature increases the oxidation rate which ultimately reduces the tensile strength of the cast alloy.
- Maximum tensile strength 299.8 MPa was obtained with the specimen cast at pouring temperature 700°C.
- With the increase in pouring temperature of the melt percentage elongation increases. But beyond 700°C of the melt the cast alloy shows less ductility. As pouring temperature increases solidification rate increases and grain size becomes smaller. So % elongation increases. Hence, ductility of the cast alloy increases. But at higher pouring temperature higher oxidation rate reduces the ductility of the cast alloy.
- Maximum ductility was observed with the specimen cast at pouring temperature 700°C.
- As the pouring temperature increases the hardness of ZA-27 alloy increases.
- Maximum hardness 54.3 was obtained with the specimen cast at pouring temperature 750°C.
- The best combination of mechanical properties for the alloy ZA-27 cast in metal mould was obtained at melt pouring temperature 700°C and mould preheat temperature 300°C.

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