EFFECT OF ADDITION OF HAFNIUM (HF) ON THE MECHANICAL BEHAVIOR AND WEAR RESISTANCE OF ZINC-ALUMINUM ALLOY5, ZA5

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Abstact

Zinc Aluminum alloys in general are versatile materials which are widely used in industrial and engineering applications due to their good resistance to wear and corrosion. These alloys solidify in large grain dendritic structure which negatively affects their mechanical strength and surface quality. Therefore, they are normally grain refined by some rare earth elements e.g Ti, Ti+B or Zr. The effect addition of these elements on the microstructure, mechanical characteristics, impact strength, wear resistance and fatigue life has been reviewed and presented by the first author in FAEM-2006. To the best of the author's knowledge the effect of Hafnium, Hf, on the metallurgical and mechanical behavior have not been investigated. In this paper, the effect of addition of Hafnium (Hf) at different weight percentages ranging from 0.02% to 0.12% to ZA5 as a grain refiner on its micro structure, hardness, mechanical behavior and wear resistance, is presented and discussed. The effect of addition of Hf at a rate of (0.02%, and 0.12%) to ZA5 alloy resulted in refining the dendritic structure of the base material, and improved its micro hardness. The effect of addition of Hf at a rate of (0.10% and 0.12%) to ZA5 resulted in slight improvement of its mechanical behavior by 0.4% and 0.2% respectively. Regarding the effect of addition of Hf on the wear resistance of this alloy, it was found that improvement has occurred only at high load and speed, namely at 20 N and 153.467 m/min speed and addition of (0.10% Hf) to ZA5 alloy resulted in the best wear resistance as compared to other added percentages.

Keywords:
Hafnium, addition, wears resistance, Zinc-Aluminum Alloy 5

1. INTRODUCTION

Zinc-Aluminum casting alloys are versatile materials which are used in many industrial and engineering applications. The main use of these alloys is for die casting, due to their low melting points, which ranges from 375°-487°C. Because of their low melting points, zinc alloys are adaptable to casting in a wide variety of moulds: plaster, metal, graphite, and even silicon rubber. Die casting is by far the most important casting process, with the following characteristics: good fluidity, pollution free melting and high strength in addition to their high corrosion resistance with die materials due to the formation of a hard protecting oxide layer, [1].

The phase diagram of zinc-aluminum alloys indicates that the larger dendrites of primary ά can be formed during solidification or homogenization of the cast, which tends to deteriorate their mechanical properties and impact strength. This effect can be overcome by adding certain alloying elements e.g. Ti or Ti+B. The relation between the mechanical properties and micro structure of cast zinc-aluminum alloy was investigated and indicated that the tensile strength of the alloy increase with the decrease of the dendrite arm spacing and the elongation increased with decreasing grain size [2, 3, 4, and 5].
Experiments show that the grain refining properties are achieved at a lower level in the presence of boron, although boron itself is not a grain refiner. For this reason, the ternary Al-Ti-B master alloy with Ti : B ratio of about 5 : 1 have been developed and now available commercially. On the other hand the presence of some alloying elements either as impurities or additives e.g. Zr, Ta may cause the grain refining effect to deteriorate. This effect is generally referred to as poisoning effect. This term is also used when the Zn alloys are difficult to be grain refined or when the grain size obtained in the alloy is coarser in the presence of the alloying element than when it absent [2].

It should be pointed out that a Ti-B modified ZA-27 alloy has developed an improvement in ductility by grain refinement with no adverse effect on strength [5].
The industrial applications of Zn-Al alloys are widely spread and well documented in the literature. Zinc-Aluminum alloy has replaced the high cost bronze in casting of bearings with 50 percent saving in weight and better wear resistance.
The effect of micro alloying these alloys by refractory metals e.g. Ti, Mo, V, B, Ta and Zr to grain refine their structure is reported in [5, 6, and 7].
Abdel-Hamid and Zaid [8] have also investigated the effect of vanadium addition on mechanical behavior, machinability and wear resistance of Aluminum grain refined by Ti+B. They found the addition of Vanadium to Al-0.045Ti – 0.01B alloy up to 0.2% has enhanced its hardness, mechanical strength and its resistance to wear. furthermore, it was found that the mechanism of wear changes from adhesive to abrasive wear at higher values of vanadium content (>0.2%), where the 0.2% V alloy suffered less wear rate than the 0.3% V alloy.
Recently Zaid and Hussein [9] and Zaid and Al-Dous [2] investigated the effect of addition of either titanium or zirconium or both of them together on the hardness of ZA5 alloy, and found that addition of either titanium or zirconium to the alloy improves its Vickers hardness. The enhancement is being more pronounced in the case of Zr addition as an increase of 11 percent was achieved, which may be attributed to the hard particles of the inter-metallic compounds $ZrAl_3$ in case of Zr addition compared to the softer particles of $TiAl_3$ in case of titanium addition. Furthermore, they reported that addition of both Ti and Zr together to the ZA5 alloy resulted in decrease of the alloy hardness which emphasizes the poisoning effect of Zr addition in presence of Ti. This means that the effect of their existence together is not additives. This was also previously reported by, Zaid and Hussain [10].

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1 Materials

The materials used through the experimental work is zinc - aluminum alloy, ZA5, having the following wt. % of 4.3 Al, 1 Cu, 0.08 Mg, 0.1 Fe, 0.005 Pb, 0.004 Cd, 0.003 Sn and the remainder Zn. High purity hafnium powder (Hf) was used as alloying element to prepare the Al-Hf master alloy.

2.2 Experimental procedures

2.2.1 Preparation of the master alloy

The pure aluminum wires were degreased and placed in a graphite crucible and charged into the electric furnace at 1100 °C for 10 minutes, taken out of the furnace and the pure hafnium powder, wrapped in aluminum foil was introduced into the crucible under cryolite flux to avoid oxidation and stirred for one minute with a graphite rod and returned to the furnace at 1100°C for 30 minutes. Finally the crucible was taken out of the furnace, stirred for one minute and spread over a thick cast iron plate to solidify in pieces of less than 5 mm thickness. The weight percentage of Hf in the master alloy was determined using scanning electron microscope (SEM)**,** type DSM950, and found to be 6.525 %.

2.2.2 Preparation of the ZA5Hf micro alloys

A set of six ZA5Hf micro alloys was prepared having the following Hf weight percentages: 0.02, 0.04, 0.06, 0.08, 0.10 and 0.12, as follows:The pre-calculated amount of the ZA5 alloy was placed in the graphite crucible and heated in the electrical furnace to 600 °C for 20 minutes. After that the crucible was taken out and the pre-calculated amount of the master alloy was placed in aluminum foil and introduced to the crucible, brought back to the furnace for 10 minutes and finally brought out and the melt is stirred using a graphite rod for 1 minute and poured to solidify in hollow thick brass cylinders.

2.3.3 Metallurgical and mechanical examinations of the different micro alloys

One specimen from each micro alloy was cut and prepared for metallurgical examination by mounting, grinding with different grades of emery paper, polished and etched by 2%HNO_3+98% Ethanol for a period of 15 seconds. Metallurgical examination was carried out using a microscope equipped with camera at magnification of X200 which enabled the determination of the grain size of each micro alloy. To investigate the effect of Hf addition on the mechanical behavior of the ZA5 alloys, one specimen of the ZA5 and its micro alloys of 9mm diameter and 9mm height were prepared. The compression test was carried out on each specimen using the universal testing machine at a cross head speed of 10 mm/min, up to 33% reduction height. The load-deflection curve was obtained for each micro alloy, from which the representative stress-representative strain for each micro alloy was obtained.

Microhardness tests were carried out using HIGHWOOD HWDM-3 Vickers Hardness Tester at 100 gm load. Six different values were taken at different locations on each specimen, from which the average HV for each micro alloy was determined.

2.3.4 Wear tests

The wear tests were carried out on a pin-on-rotating disk apparatus. The disk was made of carbon steel, thermally sprayed with an abrasive material, having a hardness of 65 HRC. The wear tests were carried out at three different speeds namely 55, 125, and 287.5 rpm at a track radius of 85 mm giving linear velocities of 29.359 m/min, 66.725 m/min, and 153.467 m/min respectively, and at three different loads of 5, 10, and 20 N. Each test was carried out for 15 minutes for a total period of 60 minutes. The pin weight was measured at the beginning and after each 15 minutes. The accumulated mass loss was obtained after one hour from which wear rate was determined, using the following equation:

$$K=V*3H/PD \quad (1)$$

Where:

K: Wear coefficient

V: Volume of removed material

H: Hardness Value

P: Applied load

D: Travelling distance

3 RESULTS AND DISCUSSION

3.1 Effect of Hf on the microstructure of ZA5 alloy

It can be seen from figure 1 that ZA5 cast alloy solidifies with a coarse dendritic structure which refers to α slow eutectoid reaction. Therefore it was difficult to determine the grain size of ZA5 due to the presence of the inter-metallic phases, eutectic phases and the dendritic structure itself. Furthermore the grain boundaries were not clearly defined; hence, the effect of Hf addition as a grain refiner can be judged from comparison of the general microstructure indicated by the photomicrographs of these figures, namely from 1 to 7 inclusive

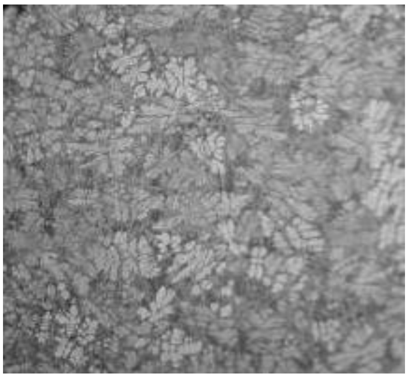

Figure 1: Photomicrograph showing the general microstructure of ZA5, X200

Figures 3 to 9 inclusive show the effect of addition of Hf in weight percentages ranging from 0.02% to 0.12% in steps 0.02% on the grain size and the general microstructure of ZA5 alloys, under the same conditions and magnification of X200 to allow comparison.

The addition of 0.04%, 0.06%, 0.08% and 0.10 % Hf resulted in modifying the structure of ZA5 alloy from coarse dendritic structure to very fine nodular grains, as shown in figures 3, 4, 5, and 6 respectively, while in case of addition of 0.02% and 0.12% Hf, the micro structure remained dendritic as shown in figures 2 and 7, but finer than the original micro structure of ZA5 alloy shown in Figure 1.

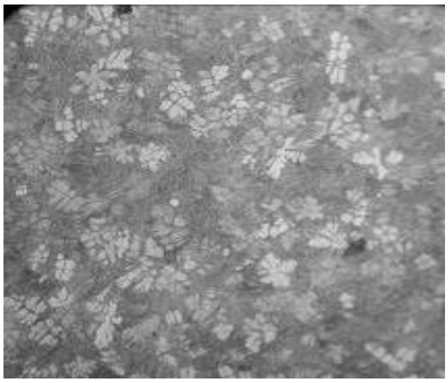

Figure 2: Photomicrograph of the general microstructure of ZA5+0.02%Hf, X200

Figure 3: Photomicrograph of the general microstructure of ZA5+0.04%Hf, X200

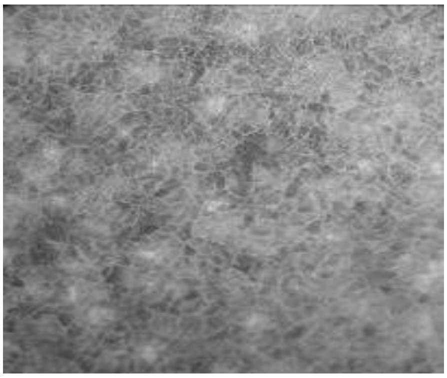

Figure 4: Photomicrograph of the general microstructure of ZA5+0.06%Hf, X200

Figure 5: Photomicrograph of the general microstructure of ZA5+0.08%Hf, X200

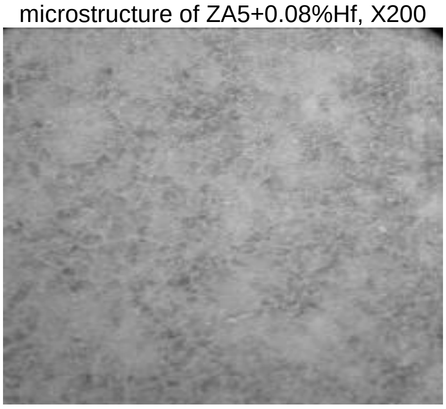

Figure 6: Photomicrograph of the general microstructure of ZA5+0.10%Hf, X200

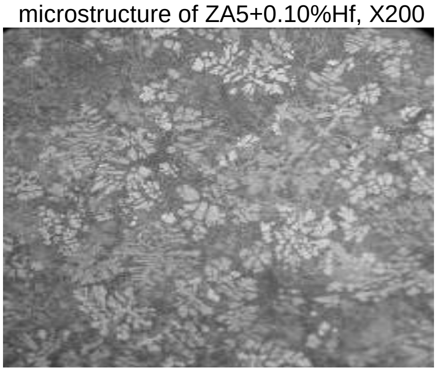

Figure 7: Photomicrograph of the general microstructure of ZA5+0.12%Hf, X200

3.2 Effect of Hf addition on the micro-hardness of ZA5 alloy

The effect of addition of Hf on the micro hardness of ZA5 alloys is clearly shown in the histogram of figure 8.It can be seen from this figure that addition of Hf to ZA5 at any weight percentage resulted in slight improvement of its micro-hardness where the structure has changed from coarse dendritic into nodular type. However, for the micro alloys where the structure remained dendritic but of finer grain size namely, addition of 0.02% and 0.12% figures 2 and 6 respectively resulted in higher hardness as clearly shown in the histogram of figure 8. This may be attributed to the different type of micro structure and the inter-metallic phases existing in the main matrix of the ZA5 alloy.

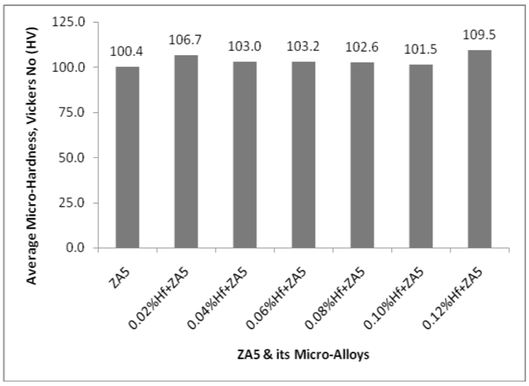

Figure 8: Average micro hardness number of ZA5 and micro-alloys

3.3 Effect of Hf addition on the mechanical behavior of ZA5 alloy

The effect of Hf addition on the mechanical behavior of ZA5 alloy is shown in figure 9 as the representative stress-representative strain curves. The flow stress at 20% strain was determined for ZA5 and its micro alloys and shown in the histogram of figure 10, from which it can be seen that addition of Hf with 0.02%, 0.04%, 0.06% and 0.08% resulted in very slight reduction of the flow stress: 2%, 3.1%, 7.8% and 3.2% respectively. However, the addition of Hf with 0.10% and 0.12% resulted in slight improvement of the flow stress: 0.4% and 0.2% respectively. Regarding the effect of Hf addition on the work hardening index, n, it can be seen from table 2 that it increased slightly, by 1%, at addition of 0.02% weight Hf but reduced by different values at the addition of other percentages namely by 5.8%, 4.6%, 7.7%, 0.75% and 4.2% for addition of 0.04%, 0.06%, 0.08%, 0.10% and 0.12% weight of Hf respectively.

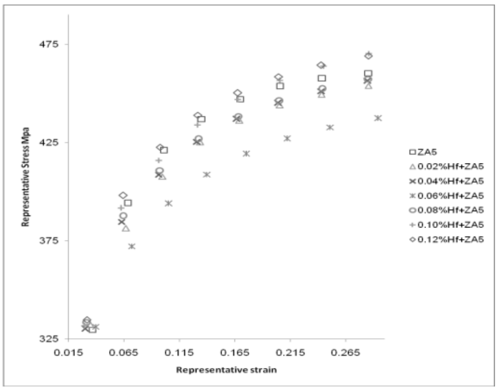

Figure 9: Effect of Hf on the representative stress representative strain of ZA5 and its micro alloys

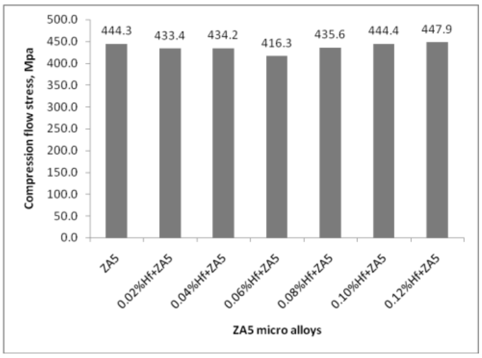

Figure 10: Effect of Hf addition on the compressive flow stress at 20% strain

3.4 Effect of Hf addition to ZA5 on its wear resistance

The effect of Hf addition on the wear resistance of ZA5 and its different micro alloys were investigated under different loads and speeds and represented as accumulated mass loss after one hour versus Hf% weight, figures 11, 12 and 13. It can be seen from figure 11 that at low speed, 29.33 m/min, and loads of 5 N, 10 N and 20 N addition of Hf to ZA5 at any rate within the experimental range, resulted in decrease of its wear resistance except at 0.1% addition.

Increasing the speed to 66.75 m/min at load 5 N did not change the trend. Doubling the load to 10 N at this speed resulted in further decrease of its wear resistance except at 0.10% Hf addition.

Exceeding the load to 20 N resulted in pronounced enhancement of wear resistance except at the small percentages. Addition of 0.02% and 0.04% Hf as indicated in figure 12.

Furthermore, it can be seen from figure 13 that increasing the speed to 153.47 m/min, even at the small loads, 5 N and 10 N addition of Hf to ZA5 at any rate except at 0.02% resulted in enhancement of its wear resistance. At higher loads, e.g.; 20 N the wear resistance has further improved. Hence, it can be concluded that the effect of addition of Hf to ZA5 on its wear resistance becomes at severe wear conditions of speed and load.

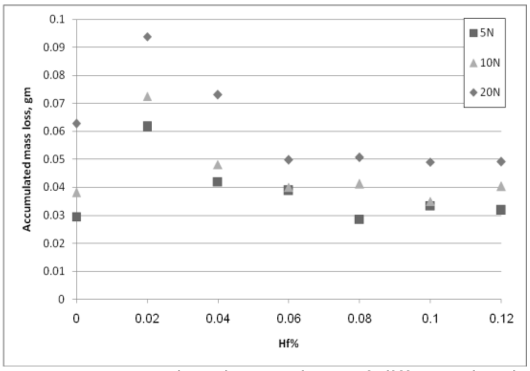

Figure 11: Accumulated mass loss of different loads at 29.359 m/min for different ZA5 and its micro alloys

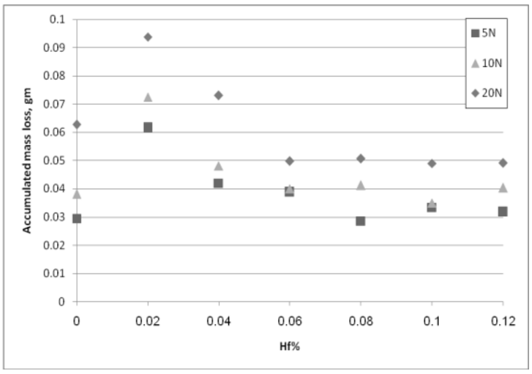

Figure 12: Accumulated mass loss of different loads at 66.725 m/min for ZA5 and its micro alloys

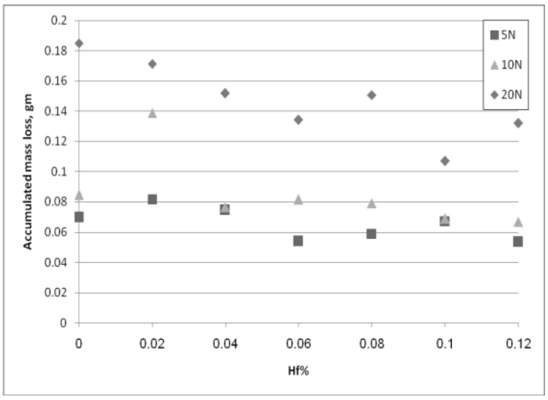

Figure 13: Accumulated mass loss of different loads

3.5 Effect of Hf addition on the wear coefficient of ZA5 alloy

In general, the hardness of the material is normally considered the most important parameter which affects wear resistance, and is included in Archard`s equation in determining the wear coefficient, k.

This equation was used to determine the coefficient of wear for ZA5 and its different micro alloys and presented tables 3, 4 and 5.

It can be seen from these tables that addition of Hf to Za5 at any rate except at 0.1% which corresponds to the peritictic limit at l load 10 N and, 29.33 m/min speed results in increase of the wear coefficient, k, i.e. reduction in wear resistance and becomes more effective at higher loads and speeds as Hf addition resulted in pronounced enhancement of wear resistance as indicated by the decrease of wear coefficient, k.at load of 2o N and speed of 153.47 m/min , Tables 3 and 4.

Table2: Effect of Hf addition on Za5 alloy wear resistance at 10 & 20 N and at speed 29.33 m/min

K	29.33 m/min	
material	10 N	20 N
ZA5	0.0000306	0.0000332
0.02Hf+ZA5	0.0000758	0.0000706
0.04Hf+ZA5	0.0001063	0.0000716
0.06Hf+ZA5	0.0000505	0.0000360
0.08Hf+ZA5	0.0000731	0.0000404
0.10Hf+ZA5	0.0000504	0.0000382
0.12Hf+ZA5	0.0000792	0.0000449

Table 3: Effect of Hf addition on Za5 alloy wear resistance at 10 & 20 N loads and at speed 66.75 m/min

K	66.75 m/min	
material	10 N	20 N
ZA5	0.0000456	0.0000374
0.02Hf+ZA5	0.0000919	0.0000595
0.04Hf+ZA5	0.0000590	0.0000447
0.06Hf+ZA5	0.0000491	0.0000305
0.08Hf+ZA5	0.0000503	0.0000309
0.10Hf+ZA5	0.0000422	0.0000295
0.12Hf+ZA5	0.0000524	0.0000320

Table 4: Effect of Hf addition on Za5 alloy wear resistance at loads10 & 20 N and at speed 153.47 m/min

K	153.47 m/min	
material	10 N	20 N
ZA5	0.0000440	0.0000480
0.02Hf+ZA5	0.0000766	0.0000472
0.04Hf+ZA5	0.0000407	0.0000404
0.06Hf+ZA5	0.0000435	0.0000358
0.08Hf+ZA5	0.0000420	0.0000399
0.10Hf+ZA5	0.0000361	0.0000281

3. CONCLUSIONS

The following points are concluded:

1. Addition of Hf to ZA5 at any rate from 0.02% to 0.12% resulted in grain refinement of its microstructure from coarse dendritic into fine nodular type at 0.04%, 0.06%, 0.08% and 0.10% and remained dendritic type but finer than the original structure at 0.02% and 0.12% Hf addition.
2. Addition of Hf to ZA5 alloy at any rate from 0.02% to 0.12% resulted in improvement of its hardness but resulted in deterioration of its mechanical behavior except at 0.12% and caused decrease in its work hardening index except at 0.02% of Hf addition.
3. Addition of Hf to ZA5 alloy at any rate resulted in decrease of its wear resistance i.e. increase of the wear coefficient at small loads and low speeds, whereas at high speeds and all loads resulted in pronounced enhancement of its.

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