Review of Microstructures and Properties of Felled Metal Alloy Composites (Al-17Si-Gr-C_f)

MANAS MAYANK[1], DR. MANISH GANGIL[2]

M.Tech.Scholar[1], *Professor*[2]

mail2manas80@gmail.com[1], rkdfbhojpal@gmail.com
Department of Mechanical Engineering, RKDF, University Bhopal, (M.P.) India.

[1]manasmayank21@gmail.com, [2]rkdfbhojpal@gmail.com,

* Corresponding Author: Manas Mayank Manuscript Received: Manuscript Accepted:

Abstract: According to market data, about 15% of world metal alloys composite consumption is devoted to the production of metal alloys composite that are used for manufacturing automotive parts, electronic/electrical systems and also, water taps and sanitary fittings, household articles, fashion goods, etc. These alloys are characterized by low melting points and high fluidity that make them suitable for foundry applications. Typically, they are processed by hot chamber high-pressure die-casting where can be cast to thicknesses as low as 0.13 mm. The die-cast metal alloys composite alloys possess an attractive combination of mechanical properties, permitting them to be applied in a wide variety of functional applications. However, depending on the alloying elements and purposes, some metal alloys composite can be processed also by cold chamber die-casting, gravity, or sand casting as well as spin casting and slush casting. In this paper, a detailed overview of the current knowledge in the relationships between processing, microstructure and mechanical properties of metal alloys composite will be described. In detail, the evolution of the microstructure, the dimensional stability and aging phenomena are described. Furthermore, a thorough discussion on mechanical properties, as such as hardness, tensile, creep, and wear properties of metal alloys composite is presented..

Keywords: Metal alloys, zamak alloy, ZA, aging

I. Introduction

A metal alloy composite is the fourth metal in the world, after iron, aluminum and copper. In 2018, the global metal alloys composite supply increased up to 13.4 Mt with a global demand of 13.77 Mt [1]. Significant amounts of metal alloys composite are also recycled and secondary metal alloys composite production is estimated in the order of 20–40% of global consumption [2]. However, because of the strict limitation on impurities in die-casting composition standards, almost all metal alloys composite die-casting alloys are prepared from primary metal alloys composite production .In general, about a half of the consumed metal alloys composite finds its application in the galvanizing steel, preventing corrosion [3]. Other important applications involve the use of metal alloys composite for other coatings, or as alloying element in brasses, bronzes, aluminum, and magnesium alloys. Metal alloys composite is exploited also as oxide in chemical, pharmaceutical, cosmetics, paint, rubber, and agricultural industries. Recently, metal alloys composite have been investigated as a promising alternative to iron and magnesium as new biodegradable metal [4]. However, about 15% of world metal alloys composite is used as base metal for the production of metal alloys composite-base alloys [5].
Some of them are available on the market as wrought alloys, in the form of flat-rolled, wire-drawn, and extruded and forged products. They are applied in the construction field for the production of roofing, downspouts, gutters, flashlight reflectors, parts for lamps, etc. Lately, a new metal alloys composite alloy for extrusion and forging has been also developed [6]. Metal alloys composite-base alloys a series of properties that makes them particularly attractive for die-casting manufacturing and, in general, for foundry technologies. In fact, they are characterized by a low melting temperature, resulting in low energy consumption and long die life, combined with high fluidity, that helps in filling complex mold cavities and very thin sections, typically as low as 0.75 mm or even down to 0.13 mm [7]. They show good mechanical properties, including equivalent, or often better, bearing and wear properties than conventional Cu alloys [8, 9]. Additionally, they are good finishing

and ability to be easily plated, making them more resistant to corrosion and wear and improving their aesthetic appearance. On the contrary, they from reduction in performance above 80–90 fluidity that helps in filling complex mold cavities and very thin sections, typically as low as 0.75 mm or even down to 0.13 mm [7]. They show good mechanical properties, including equivalent, or often better, bearing and wear properties than conventional Cu alloys [8,9]. Additionally, they offer good finishing and ability to be easily plated, making them more resistant to corrosion and wear and improving their aesthetic appearance. On the contrary, they suffer from reduction in performance above 80–90 °C [10] and/or after long exposure at room temperature (aging) [11]. For these reasons, they are mainly used for small non-structural components in many fields as such as automotive, hardware, electric/electronic devices, clothes, toys, sports, ornaments, etc. For instance, parts like safety belt blocks, locking mechanisms, wiper motor housings, cylinder locks, some electronic connectors, handles, tap systems, zippers; belt buckles, spring adjuster in bikes, costume jewelry, appliances, etc. are made from metal alloys composite-base alloys. For instance, parts like safety belt blocks, locking mechanisms, wiper motor housings, cylinder locks, some electronic connectors, handles, tap systems, zippers, belt buckles, spring adjuster in bikes, costume jewelry, appliances, etc. are made from metal alloys composite-base alloys & Copper is added to increase the alloy performance in terms of tensile strength, hardness and wear resistance, as well as creep behavior [16]. Usually, a small amount of Mg is also present to inhibit inter-granular corrosion [17], even if in modern practice its need is very limited because of the high purity of Zn [11] Copper is added to increase the alloy performance in terms of tensile strength, hardness and wear resistance, as well as creep behavior [16]. Usually, a small amount of Mg is also present to inhibit inter-granular corrosion [17], even if in modern practice its need is very limited because of the high purity of Zn [11] Depending on the amount of alloying elements, metal alloys composite alloys usually available on the market can be manufactured by means of different processes: hot chamber die-casting, cold chamber die-casting, gravity and sand casting, as well as spin casting and slush casting. Depending on the amount of alloying elements, metal alloys composite alloys usually available on the market can be manufactured by means of different processes: hot chamber die-casting, cold chamber die-casting, gravity and sand casting, as well as spin casting and slush casting. Die-casting involves the injection of the molten metal into a permanent die, under high pressure and high speed. This allows obtaining near-net shape castings, characterized by thin sections, tight dimensional tolerances, smooth surfaces, high production rates, etc. In particular, in hot-chamber process the injection system (including a pump that feeds a heated channel called the gooseneck) is submerged into the crucible containing the molten alloy. On the contrary, in cold-chamber die-casting the furnace is separate from the casting machine and the liquid metal is transferred into the injection system (shot sleeve) by a ladle [18]. About the 90–95% of metal alloys composite alloys are typically processed via hot-chamber die-casting technique thanks to their low melting temperature [5]. When the amount of alloying elements increases, like in the case of ZA27 or Cu Metal alloys composite 10, cold-chamber die-casting is required as a result of the associate increase in their melting temperature and attitude to attack, react with or dissolve the injection system. Die-casting involves the injection of the molten metal into a permanent die, under high pressure and high speed. This allows to obtain near-net shape castings, characterized by thin sections, tight dimensional tolerances, smooth surfaces, high production rates, etc. In particular, in hot-chamber process the injection system (including a pump that feeds a heated channel called the gooseneck) is submerged into the crucible containing the molten alloy. On the contrary, in cold-chamber die-casting the furnace is separate from the casting machine and the liquid metal is transferred into the injection system (shot sleeve) by a ladle [18]. About the 90–95% of metal alloys composite alloys are typically processed via hot chamber die-casting technique thanks to their low melting temperature [5]. When the amount of alloying elements increases, like in the case of ZA27 or Cu Metal alloys composite 10, cold-chamber die-casting is required as a result of the associate increase in their melting temperature and attitude to attack, react with or dissolve the injection system. For limited applications also gravity or sand casting are applied, where the metal is poured by gravity in a mold made in steel or refractory material respectively. Typical components produced with these technologies are press dies and punches for sheet metal forming or molds for ceramics and rubber using Kirksite (i.e., Zamak 2) [19]. For limited applications also gravity or sand casting are applied, where the metal is poured by gravity in a mold made in steel or refractory material respectively. Typical components produced with these technologies are press dies and punches for sheet metal forming or molds for ceramics and rubber using Kirksite (i.e., Zamak 2) [19]. Spin casting exploits a centrifugal force to fill a mold made of rubber. This technique is particularly suitable for low melting alloys, like some metal alloys composite-base ones, resulting in a cheap and fast method for the production of small parts, short run and prototypes for fashion industry, miniature models, fishing lures, etc Spin casting exploits a centrifugal force to fill a mold made of rubber. This technique is particularly suitable for low melting alloys, like some metal alloys composite-base ones, resulting in a cheap and fast method for the production of small parts, short run and prototypes for fashion industry, miniature models, fishing lures, etc For the production of hollow products, like some table lamp bases, also slush casting is used For the production of hollow products, like some table lamp bases, also slush casting is used [20]. It consists in pouring the liquid metal into the mold, allowing the solidification of a shell on the wall of the mold. The remaining liquid in the core is then poured out, leaving the hollow shell characterized by [20]. It consists in pouring the liquid metal into the mold, allowing the solidification of a shell on the wall of the mold. The remaining liquid in the core is then poured out, leaving the hollow shell characterized by a good surface. For this casting technology, metal alloys composite alloys with very high fluidity and narrow solidification range are needed, like those containing around 5–6% of Al and 1% of Cu [5,20]. A good surface. For this casting technology, metal alloys composite alloys with very high fluidity and narrow solidification range are needed, like those containing around 5–6% of Al and 1% of Cu [5,20]. It has to be noticed that all the above-mentioned Zn alloys do not usually undergo cold working or heat treatment to improve mechanical properties because of the risk of crack formation during cold working (low plasticity) and because of the limited effectiveness of age hardening [11]. Therefore, except some surface finishing, they are normally used in the as-cast condition. It follows that the quality of the part and their microstructure plays a major role in defining component performances. It has to be noticed that all the above-mentioned Zn alloys do not usually undergo cold working or heat treatment to improve mechanical properties because of the risk of crack formation during cold working (low plasticity) and because of the limited effectiveness of age hardening [11]. Therefore, except some surface finishing, they are normally used in the as-cast condition. It follows that the quality of the part and their microstructure plays a major role in defining component performances.

3. Microstructures

As already reported, metal alloys composite casting alloys always contain aluminum as main alloying element. Hence, in agreement with Zn-Al phase diagram (Figure Hence, in agreement with Zn-Al phase diagram, they could be distinguished in three categories: hypoeutectic (e.g., Zamak), hypereutectic (e.g., ZA12, ZEP), and hypereutectoid alloys (e.g., ZA27, Alzen 305) The hypoeutectic alloys are the most widely used in industrial applications, as they correspond to the hot-camber die-casting alloys, commercially known as Zamak. The hyper-eutectic/eutectoid ones are more devoted to cold chamber process or gravity and sand casting, covering a more restricted market. The corresponding microstructures are therefore different, depending also on the specific cooling rate related to the foundry process. The hypoeutectic alloys are the most widely used in industrial applications, as they correspond to the hot-camber die-casting alloys, commercially known as Zamak. The hyper-eutectic/eutectoid ones are more devoted to cold chamber process or gravity and sand casting, covering a more restricted market. The corresponding microstructures are therefore different, depending also on the specific cooling rate related to the foundry process. The metallographic analysis of a Zamak 5 die-cast part after Ni 2% etching is reported as an example of the hypoeutectic alloys. Primary Zn-rich dendrites (white) surrounded by the eutectic can be distinguished. The microstructure at higher magnification reveals that the eutectoid consists of platelets of Al-rich phase dispersed in Zn-rich one. As shown by the scanning electron microscope with energy dispersive spectroscopy microanalysis (SEM-EDS), This mainly retained in solid solution in the primary phase. In case of alloy containing Cu in percentage higher than 2%, like for instance in Zamak 2, also Cu-rich e-phase (CuZn) can be easily found [20].

4. Performance of Metal alloys composite Alloys

Notwithstanding that metal alloys composite alloys are used for functional, decorative and non-structural products, the knowledge about their performance is fundamental for their proper application under different service conditions. Hence, in the last decades, several studies have been focused on the investigation of mechanical, technological and electro-chemical properties of parts fabricated in metal alloys composite alloys, sometimes in comparison with other non-ferrous metals (mainly brass). The knowledge about their performance is fundamental for their proper application under different service conditions. Hence, in the last decades, several studies have been focused on the investigation of mechanical, technological and electro-chemical properties of parts fabricated in metal alloys composite alloys, sometimes in comparison with other non-ferrous metals (mainly brass). Products, the knowledge about their performance is fundamental for their proper application under different service conditions. Hence, in the last decades, several studies have been focused on the investigation of mechanical, technological and electro-chemical properties of parts fabricated in metal alloys composite alloys, sometimes in comparison with other non-ferrous metals (mainly brass).

4.1. Wear and Cavitation Resistance

Wear resistance is particularly important for Zn-base alloys due to the specific application fields of these materials, ranging from fashion and decorative (buckles, chain and belts, zippers, etc.) to automotive industry (small gears, gear racks, pulleys, gearboxes, etc.). In addition, as mentioned above, Zn alloys are often used for bearings production to replace Cu-base alloys. Therefore, sliding wear behavior of Zn-Al alloys has been widely investigated in scientific literature by means of experimental testing mainly with pin-on-disk or block-on-disk (ring) configurations and in dry or lubricated conditions.

It has to be reminded that wear resistance is not an intrinsic property of the material, as it depends on the considered tribological system and the used test conditions. Therefore, a comparison of the wear behavior of alloys tested under different conditions (i.e., different applied load, sliding distance, with or without lubrication, etc.) is not reliable. However, different authors agree about general findings.

A common point is that the microstructural features discussed in Paragraph 3 play a major role in determining wear performance of Zn-Al alloys. Considering for instance those with low Al content, hypo-eutectic Zamak 2 and Zamak 3 alloys were studied in comparison with Zn alloys with higher levels of Cu and/or Al [10]. In general, the low hardness of Zamak 3 alloy (due to the primary Zn-rich-phase) results in higher friction coefficient and wear rate than the other alloys when tested against steel counter-part in dry conditions [11]. On the other hand, Zamak 2 alloy is harder, due to the higher Cu content, but it is reported to exhibit worse wear resistance in comparison with alloys with higher Al content alloys (i.e., ZnAl15Cu1 and ZA27). This is likely due to a limited oxide formation on the wear track, especially in the first stages of the test, as shown as an example in Figure to protect the surface from damage. However, also Zamak 2 experiences a pronounced oxidation of the track by increasing the sliding distance (i.e., up to 1000 m) [12]. In all the alloys, scratches aligned with the sliding direction can be seen, as a result of the abrasive wear damage. These materials, ranging from fashion and decorative (buckles, chain and belts, zippers, etc.) to automotive industry (small gears, gear racks, pulleys, gearboxes, etc.). In addition, as mentioned above, Zn alloys are often used for bearings production to replace Cu-base alloys. Therefore, sliding wear behavior of Zn-Al alloys has been widely investigated in scientific literature by means of experimental testing mainly with pin-on-disk or block-on-disk (ring) [15,16] configurations and in dry or lubricated conditions.

It has to be reminded that wear resistance is not an intrinsic property of the material, as it depends on the considered tribological system and the used test conditions. Therefore, a comparison of the wear behavior of alloys tested under different conditions (i.e., different applied load, sliding distance, with or without lubrication, etc.) is not reliable. However, different authors agree about general findings. A common point is that the microstructural features discussed in Paragraph 3 play a major role in determining wear performance of Zn-Al alloys. Considering for instance those with low Al content, hypo-eutectic Zamak 2 and Zamak 3 alloys were studied in comparison with Zn alloys with higher levels of Cu and/or Al [18.19]. In general, the low hardness of Zamak 3 alloy (due to the primary Zn-rich η-phase) results in higher friction coefficient and wear rate than the other alloys when tested against steel counter-part in dry conditions [19]. On the other hand, Zamak 2 alloy is harder, due to the higher Cu content, but it is reported to exhibit worse wear resistance in comparison with alloys with higher Al content alloys (i.e., ZnAl15Cu1 and ZA27). This is likely due to a limited oxide formation on the wear track, especially in the first stages of the test, as shown as an example in Figure 7. On the contrary, the oxide formed on the wear track of ZnAl15Cu1 (ZEP) and ZA27 alloys seems able to protect the surface from damage. However, also Zamak 2 experiences a pronounced oxidation of the track by increasing the sliding distance (i.e., up to 1000 m) [20]. In all the alloys, scratches aligned with the sliding direction can be seen, as a result of the abrasive wear damage.

5. Summary

In the present paper, an overview of the properties of Zn alloys is provided, paying particular Attention to the identification of the correlation between microstructure and performance. In particular, after a first summary of commercial alloys and relative manufacturing processes, microstructural properties are described. In this regard, the discussion is focused on the Zn-Al and Zn-Cu systems, which are the most widely used. Subsequently, various aspects are described, as such as tensile properties, wear resistance, creep behavior, and corrosion resistance. A paragraph is also dedicated to the discussion of the effect of natural aging on material properties since Zn alloys are especially sensitive to this phenomenon. The general aim of the present discussion of properties of Zn-based alloy is to allow the reader to better understand the specific applications suitable for this family of alloys.

References

[1]. Liu, Z.; Li, R.; Jiang, R.; Li, X.; Zhang, M. E_ects of Al addition on the structure and mechanical properties of Zn alloys. J. Alloys Compd. **2016**, 687, 885–892.

[2]. Hekimo˘glu, A.P.; Sava¸skan, T. Structure and mechanical properties of Zn-(5–25) Al alloys. Int. J. Mater. Res. **2014**, 105, 1084–1089.

[3]. Pola, A.; Montesano, L.; Roberti, R. Nuove Leghe di Metal alloys compositeo per L'industria del Design. In Proceedings of the 30th Convegno Nazionale AIM, Brescia, Italy, 10–12 November 2010.

[4]. Sava¸skan, T.; Hekimoglu, A.P.; Pürçek, G. E_ect of copper content on the mechanical and sliding wear properties of monotectoid-based metal alloys composite-aluminium-copper alloys. Tribol. Int. **2004**, 37, 45–50.

[5]. Luo, X.-P.; Xia, L.-T.; Zhang, M.-G. E_ect of di_erent Al content on the microstructure, mechanical and friction properties of high aluminum metal alloys composite-based alloys. J. Adv. Microsc. Res. **2011**, 6, 301–305.

[6]. Türk, A.; Durman, M.; Kayali, E.S. The e_ect of manganese on the microstructure and mechanical properties of metal alloys composite–aluminium based ZA-8 alloy. J. Mater. Sci. **2007**, 42, 8298–8305.

[7]. Li, M.; Lu, S.; Long, F.; Sheng, M.; Geng, H.; Liu, W. E_ect of Y Addition on the Mechanical Properties and Microstructure of Zn-Al Alloys. JOM **2015**, 67, 922–928.

[8]. Gancarz, T.; Cempura, G. Characterization of ZnAl cast alloys with Li addition. Mater. Des. **2016**, 104, 51–59.

[9]. Krupi´nska, B. Structure and Properties of Zn–Al–Cu Alloys with Alloying Additives. Adv. Struct. Mater. **2015**, 70, 341–349.

[10]. Choudhury, P.; Das, K.; Das, S. Evolution of as-cast and heat-treated microstructure of a commercial bearing alloy. Mater. Sci. Eng. A **2005**, 398, 332–343.

[11] Sava¸skan, T.; Bican, O. E_ects of silicon content on the microstructural features and mechanical and sliding wear properties of Zn–40Al–2Cu–(0–5)Si alloys. Mater. Sci. Eng. A **2005**, 404, 259–269. 12. Pola, A.; Gelfi, M.; La Vecchia, G.M.; Montesano, L. On the ageing of a hyper-eutectic Zn-Al alloy. Metall. Ital. **2015**, 107, 37–41.

[12]. Goodwin, F.E.; Kallien, L. Improving the Relationship between Processing and Properties of Metal alloys composite Die Casting: Developments in Creep and Ageing Correlations. SAE Int. J. Mater. Manuf. **2011**, 4, 1188–1197.

[13]. Dorantes-Rosales, H.J.; López-Hirata, V.M.; Hernández-Santiago, F.; Saucedo-Muñoz, M.L.; Paniagua-Mercado, A.M. E_ect of Ag addition to Zn22 mass%Al2 mass%Cu alloy on the four-phase reaction. Mater. Trans. **2018**, 59, 717–723.

[14]. Chen, Y.; Tu, M. Dimensional shrinkage of supersaturated ZA27Cu1 and ZA27Cu2 alloys. Mater. Sci. Techol. **1998**, 14, 473–475.

[15]. Chen, H.; Xin, X.; Dong, D.Y.; Ren, Y.P.; Hao, S.M. Study on the stability of T0 phase in the Al-Zn-Cu ternary system. Acta Metall. Sinca **2004**, 17, 269–273.

[16]. Lee, P.P.; Savaskan, T.; Laufer, E. Wear resistance and microstructure of Zn-Al-Si ans Zn-Al-Cu alloys. Wear **1987**, 117, 79–89.

[17]. Türk, A.; Kurnaz, C.; ¸Sevik, H. Comparison of the wear properties of modified ZA-8 alloys and conventional bearing bronze. Mater. Des. **2007**, 28, 1889–1897.

18. Sava¸skan, T.; Maleki, R.A. Friction and wear properties of Zn-25Al-based bearing alloys. Tribol. Trans. **2014**,57, 435–444.

[19]. Babic, M.; Mitrovic, S.; Jeremic, B. The influence of heat treatment on the sliding wear behavior of a ZA-27 alloy. Tribol. Int. **2010**, 43, 16–21.

[20[. Pürçek, G.; Savaskan, T.; Küçükömeroglu, T.; Murphy, S. Dry sliding friction and wear properties of metal alloys composite-based alloys. Wear **2002**, 252, 894–901. 51. Hanna, M.D.; Carter, J.T.; Rashid,