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Corrosion behaviour of thixoformed and heat-treated ZA27 alloys in NaCl solution

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Abstract: The influence of corrosion on the microstructure of thixoformed and heat-treated ZA27 alloys was investigated. The microstructure of ZA27 alloy was affected by heat treatment. The process of electrochemical corrosion occurs in both ZA27 alloys through the area of *η* phase. According to the results of immersion test and electrochemical measurements, the corrosion rate of the thixoformed ZA27 alloy is at least 50% lower than that of the thixoformed and thermally processed alloy. This indicates the unfavourable influence of applied heat treatment (T4 regime) on the corrosion resistance of the thixoformed ZA27 alloy.

Key words: ZA27 alloy; thixoforming; corrosion; heat treatment; microstructure

1 Introduction

Zinc-based alloy with 27% (mass fraction) aluminium belongs to Zn–Al foundry alloys with relatively high content of aluminium (ZA alloys). The alloy is distinguished by the exceptionally high wear resistance as well as favourable physical, mechanical and technological properties (low density and melting point, high strength and hardness at ambient temperatures, easy machinability, good damping properties, high corrosion resistance) [1,2]. The alloy has been mostly used for pressure die-castings and gravity castings and can be easily cast by sand moulding, shell moulding and permanent moulding [3]. The alloy is shown to be a suitable bearing material for heavy static loads and low load/high speed applications requiring high strength, hardness and wear resistance [4]. Favourable characteristics and low manufacturing cost of ZA27 alloy enable it to compete with other cast metals such as high strength aluminium alloys, aluminium bronzes, grey iron and brass. Typical uses of the alloy include machine tools, presses, internal combustion engines, general engineering industries, transport industry, etc.

The properties of ZA27 alloy can be improved by changes in the microstructure of the alloy. The improvements in the mechanical properties, wear resistance and corrosion resistance were realized at ambient temperatures. This was achieved through the addition of some chemical elements [5,6], by using different heat treatments [7,8] or thermomechanical treatments [9,10]. At last, some special manufacturing techniques such as thixoforming [11,12] and unidirectional solidification [13,14] were applied.

Semi-solid processing has its many advantages over traditional technologies. It has already been applied to industrial production of steels, aluminium alloys and magnesium alloys. Thixoforming is a relatively new technique of metals forming in the semi-solid state [15]. This technique is based on the thixotropic behaviour of alloys with non-dendritic microstructure in the semi-solid state. During thixoforming, vigorous mechanical mixing of the cooling metal melt prevents the formation of normal dendrites and maintains the solid fraction of the melt in the form of rounded primary particles. This technique enables the production of near net-shape components with good mechanical properties at low manufacturing cost [15]. Besides a good combination of strength and ductility, the thixoformed components are heat treatable and weldable. The advantages and drawbacks of thixoforming were described in Refs. [15,16].

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ZA27 alloy solidifies in the wide temperature range and is suitable for processing in the semi-solid state. The as-cast alloy is characterised by typical dendritic structure and non-uniform distribution of chemical elements in the alloy phases [17−19]. Traditional casting techniques such as die-casting and permanent mould casting were substituted by thixoforming in order to achieve non-dendritic structure and favourable mechanical properties of the alloy [11,12,20].

The microstructure and properties of ZA27 alloy can also be influenced by the appropriate heat treatment. Ductility [21−23] and sliding wear behaviour of the conventional Zn–Al alloys were improved after thermal treatment [21,24], while their hardness [21,22,24] and tensile strength [21−23] were reduced. It was shown that T4 regime had a beneficial effect on the ductility [25] and tribological characteristics of ZA27 alloy [26,27], although it resulted in minor reduction in hardness and tensile strength [26]. The microstructure of as-cast ZA27 alloy was changed because of the heat treatment. The improved distribution of micro constituents and reduced tendency of forming micro-cracks were achieved [25,27].

The microstructure has a profound influence on the corrosion behaviour of an alloy [28]. It was shown that heat treatment (T4 regime) affected the microstructure and corrosion resistance of as-cast ZA27 alloy [29]. However, there were no results reported so far concerning the effect of T4 regime on the microstructure and corrosion behaviour of the thixoformed ZA27 alloy.

Due to the low melting point [2], ZA27 alloy suffers from deterioration in mechanical properties above 100 °C. It was shown that particulate composites with base ZA27 alloy preserved favourable mechanical characteristics at higher operating temperatures [30]. The composites were obtained by compocasting process through infiltration of ceramic particles into the semi-solid melt of the matrix alloy.

The physical and mechanical characteristics of metal-matrix composites, as well as their corrosion behaviour, are determined by the properties of the matrix alloy [31]. The microstructure of particulate composites with matrix ZA27 alloy is very similar to the microstructure of the thixoformed ZA27 alloy [30].

High corrosion resistance of ZA27 alloy in the natural atmospheres and natural waters is well known [32]. The most common form of corrosion in these environments is general corrosion. The immersion method and electrochemical polarization measurements have been used frequently in corrosion studies to assess the rate of general corrosion [32]. Most corrosion studies were performed in the neutral chloride solutions opened to the atmosphere because chloride ions and dissolved oxygen are present in many corrosive environments and because of great influence of dissolved oxygen on the corrosion mechanism and kinetics of zinc and zinc alloys [33].

In this work, the influence of corrosion on the microstructure of the thixoformed ZA27 alloy was studied. A comparative study was also conducted on the thixoformed and thermally processed ZA27 alloy, to assess the effect of the applied heat treatment on the microstructure and corrosion resistance of the thixoformed ZA27 alloy.

2 Experimental

2.1 Materials

The chemical composition of ZA27 alloy used in this work is given in Table 1. The chemical composition of the alloy is in accordance with the EN standard [34].

Table 1 Chemical composition of ZA27 alloy (mass fraction, %)

Al	Cu	Mg	Fe	Sn	Cd	Pb	Zn
26.3	1.54	0.018	0.062	0.002	0.005	0.004	Bal.

The alloy was obtained by conventional melting and casting route in the Department of Materials Science ″Vinča″ Institute. The alloy was poured at 570 °C into the steel mould preheated up to 100 °C. The as-cast samples with size of 20 mm×30 mm×120 mm were obtained.

Thixoforming of the ZA27 alloy was performed in order to achieve the permanent transformation of dendritic into the non-dendritic structure. The process was conducted in two phases. In the first phase, the semi-solid melt of the ZA27 alloy was exposed to shear forces (caused by mechanical mixing), to break down the dendritic structure of the as-cast alloy completely. Hot pressing was applied in the second phase in order to reduce the porosity of the thixoformed samples.

The as-cast ZA27 alloy was charged into the crucible of the electro-resistance furnace. It was melted and overheated to 580 °C to clean the slag from the melt surface. The melt was left to cool down to 485 °C at 5 °C/min cooling rate (approximately isothermal regime). The active part of the paddle stirrer was then immersed into the semi-solid melt. Mixing of the melt was performed in the temperature range between liquidus and solidus temperatures with a gradual increase in mixing speed. Stationary mixing regime (i.e. mixing at constant temperature and constant mixing speed) was achieved at 461 °C and 450 r/min. The combination of slow and intensive mixing was applied during thixoforming. Thixoforming at 450 r/min lasted 5 min to break down dendrites in the structure of the as-cast alloy. Mixing