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Effects of die core treatments and surface finishes on the sticking and galling tendency of Al–Si alloy casting during ejection

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ABSTRACT

In the process of high pressure die casting of aluminium alloys tool surfaces are severely damaged by cast alloy sticking and soldering which promote galling during casting ejection. As a consequence, casting quality is lowered and production efficiency is reduced. Although die casting tools are greatly improved by application of diffusion layers and surface coatings, effects of surface topography on performance of such treated tools are scarcely recognized. This investigation gives an insight in the effects of surface topography on the sticking tendency and galling of Al–Si alloy toward the H11 steel, plasma nitrided steel, and duplex treated steel with CrN and TiAlN PVD top coatings. The sticking tendency was evaluated by ejection test during which the force required to eject the sample from the casting was measured. It was found that the ejection force does not depend on chemical composition of the investigated materials. However, the ejection force of coated samples strongly depends on their surface topography. The coated samples which were polished after the deposition exhibited the highest ejection force. Wear conditions inherent in this specific tribo-system are recognised and interpreted for surfaces with different topography.

1. Introduction

On the market of a highly competitive aluminium processing industry establishing a cost effective production is an ever challenging task which can be achieved through various strategies. One of them is maintaining the product quality and lowering the production cost by increasing the production efficiency and reduction of production downtime. In hot processing of aluminium alloys this involves particular efforts in reduction of the tool failures caused by harsh operating environment.

High pressure die casting is one of the most commonly applied technologies for hot processing of the aluminium alloys. In this process, liquid metal is injected into a steel die (tool) at high velocity and pressure. At the end of the filling stage the pressure is intensified, the casting is forcibly cooled in the die, and upon the completion of solidification it is ejected from the die. This process is characterized by high temperatures, high melt velocities and high pressures, mechanical and thermal fatigue, chemical and mechanical interaction of casting and die materials [1–4]. Although die lubricants are applied on the working surfaces, these harsh conditions cause damage on tool surface due to the complex chemical, metallurgical and mechanical processes involved [4,5]. Depending on the dominant operating mechanism different failure modes are distinguished: die soldering (corrosion and sticking), washout (erosion) and heat checking (thermal fatigue cracking) [2,4–6].

Nowadays, in the aluminium die casting production die soldering becomes a major concern [7–9]. Soldering affects casting quality, shortens the die life, deteriorates production efficiency and causes serious downtime due to increased tool maintenance [2,7,9]. This phenomenon refers to the formation of cast material built-up layer on die surfaces. The built-up forms by mechanical interaction of cast material with die surface or by chemical-metallurgical reactions on the casting-die interface [3,9]. Mechanical soldering or cast alloy sticking is dependent on surface morphology and local pressure while metallurgical soldering is a process driven by chemical reactions and diffusion [1,5,9]. Metallurgical soldering results in formation of an intermetallic layer which grows both inward and outward the die material [1]. In this way, a strong bond between casting and die is established which hampers easy casting ejection. As a consequence of the soldering phenomena, high ejection force could cause bending of casting or ejector [2], drag marks form on the casting, and lastly casting loses dimension tolerances [10]. Soldering is the most pronounced on die cores or pins that form narrow and deep holes (or openings) in casting [2]. These elements are

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difficult to cool and due to overheating become susceptible to metallurgical soldering. Sometimes the tolerances of features formed by such cores are very narrow, e.g. 0.04 mm. Therefore, it is essential to maintain their dimensions on a long run.

In order to tackle the problem of die casting tools wear, over the past two decades, numerous investigations concerned the development of surface engineering technologies and their implementation into industrial practice [4,11–22]. Plasma nitriding and physical vapour deposition (PVD) emerged as the most appropriate technologies for formation of protective layers on hot-working tool steels. Although plasma nitrided layers are characterised by high wear and thermal fatigue resistance [4], they have thermal and oxidation resistance limited to 520 °C [16,23,24]. On the other hand, due to their high hardness and toughness, PVD coatings provide higher resistance to erosive and abrasive wear [17,25], while their high oxidation resistance and chemical inertness in liquid aluminium assure adequate resistance to corrosion and anti-sticking properties [11,17]. However, PVD coatings fail under high cyclic thermal stresses generated during the die casting process [16,17]. For this reasons application of PVD coatings on previously plasma nitrided layers was established as the most appropriate treatment (duplex surface treatment) of the tools subjected to complex conditions present in high pressure die casting of aluminium alloys [11,16,17].

Numerous investigations related to the coatings soldering in molten aluminium (immersion tests), have shown that PVD coatings largely outperform the hot-working tool steels [18,26]. Although coatings do not react with aluminium, they fail during the longer exposures to the molten alloys [18,26]. The failure starts around coating growth defects where the coating delamination is initiated by substrate corrosion [18,26,27]. Another type of failure is caused by thermal fatigue cracks which directly expose the underlying substrate to the molten aluminium [11,28]. These soldering mechanisms refer to the coating metallurgical soldering, which have detrimental effect on the coating integrity and lead to the tool segment replacement or recoating. On the other side, in the majority of investigations conducted by die casting trials the cast alloy sticking was evidenced on the coated segments [7,8,19,20]. These investigations have shown that surface topography has a substantial effect on the casting sticking tendency toward the coated surfaces [7,19]. Therefore, the observed sticking process draws special attention because it affects galling during ejection and consequently castings quality and production efficiency.

During the development of surface engineered layers practical evaluation of soldering tendency in laboratory conditions is done using the ejection test [10,11,15]. This test simulates the ejection process of a pin-shaped part (sample) from the casting. Accordingly, the force needed to perform the sample ejection represents a measure of soldering/sticking tendency between paired materials [10,11]. Such test arrangement is justified by the fact that the pin-shaped die elements (cores) are predominantly exposed to the soldering phenomena and to the shearing force during the part ejection. Investigations concerning soldering of aluminium alloys presented in references [10,11,15] reported that plasma diffusion layers exhibit lower ejection force than the heat treated hot-working tool steel (H13). However, the lowest ejection force is recorded for different kinds of PVD transition metal-nitride hard coatings [10,11]. The observed values of ejection force conform to the degree of aluminium affinity toward the chemical elements of investigated surfaces. Still, when pin-casting assemblies are produced by usually used procedures (presented in [10,11]) the irregularities in the pin-casting contact can easily form. Consequently, the real exploitation conditions are insufficiently reproduced and large experimental scatter is expected due to the low repeatability. In addition, the effects of surface topography on the wetting, soldering (sticking) and galling conditions are not considered in the most representative investigations from the field [10,11,15]. Accordingly, interpretation of the ejection force and involved tribological processes are inaccurate and could lead to false conclusions. In order to appropriately exploit the advantages of PVD coatings for high pressure die casting tools it is of great importance to understand the effects of surface topography on their performances.

The aim of this study was to evaluate the sticking tendency and galling of Al–Si alloy toward the hot-working tool steel (H11), plasma nitrided and duplex treated surfaces by application of the improved ejection test. Special attention was given to the influence of surface roughness and topography on samples ejection performance. The effects of topography on sticking tendency and galling were thoroughly investigated for duplex treated samples with CrN and TiAlN coatings.

2. Material and methods

All samples used in this research were made of quenched and double tempered H11 hot-working tool steel. The investigated surface layers on H11 steel were produced by plasma nitriding and duplex treatment (plasma nitriding + deposition of CrN and TiAlN PVD coatings). The following operations were performed sequentially during the sample production: 1. steel sample preparation and surface finishing; 2. plasma nitriding; 3. compound layer removal by polishing; 4. deposition of PVD coatings and post deposition polishing if applied. After each operation a representative group of samples was determined. Particular procedures used for sample preparation are explained in detail in the following subsections.

2.1. Sample fabrication and surface preparations

The samples were made in two shapes. Typical disk shaped samples, with dimensions of $\phi 20\times 5$ mm, were used for the assessment of coatings properties. The samples used in the ejection tests were cylindrical pins with dimensions of $\phi 15\times 100$ mm (Fig. 1). Heat treatment was carried out by austenitising for 30 min at 1000 °C which was followed by oil quenching and double tempering for 1 h at 620 °C and for 1 h at 500 °C. In order to replicate surfaces of real tool parts, the investigated samples were prepared by procedures regularly conducted in manufacturing practice of die casting tools. Three surface finishing procedures were employed to prepare the pin samples to a different grades of surface roughness. According to the preparation method the samples were assigned into three groups and these are: 1. rough pins; 2. smooth pins and 3. post polished pins (see Table 1). The rough pins were produced of fine ground H11 steel samples which were further subjected to plasma nitriding. The initial surface finish of the rough coated samples was obtained by polishing the rough plasma nitrided samples with a 6 μm diamond paste. The smooth samples were produced of a fine ground H11 steel polished with 6 μm and 3 μm diamond paste further subjected to plasma nitriding. Before coatings deposition the smooth plasma nitrided surfaces were subjected to polishing with a 3 μm diamond paste. The post polished samples

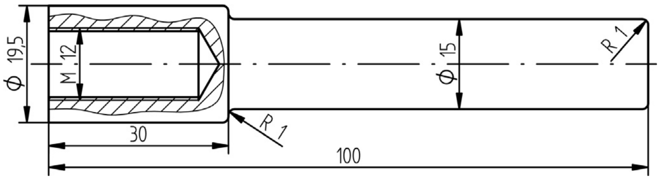

Fig. 1. Drawing of the pin shaped sample used for the ejection tests.