Possibilities of improving the durability of pressure moulds

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Abstract
This study analyses factors that influence the durability of pressure moulds. Materials for pressure moulds are also characterized here, as well as methods of refining moulds by applying coats which create a thermal and anti-erosion barrier.

Key words: pressure mould, thermal and anti-erosion barrier

1. Introduction

Works conducted to prolong the life-span of pressure moulds are substantial for foundry practice, which is noticeable in a list of roadmaps conducted or prepared for implementation by teams and associations of American founders [1,2], as well as research teams in various countries of the European Union [2,3]. In Poland, the problem of pressure foundry, including moulds, has been dealt with by many researchers. Problems concerning pressure foundry have been presented in numerous books [4-11]. Such works are also conducted by a research team of Die-casting Foundry META-ZEL.

2. Factors that influence pressure mould wearing

At pressure casting, there are flows of liquid alloy in the gate system, under the pressure of between 500 and 800 bar and a velocity between 30 and 60 m/s. In the gate system areas and in the mould cavity areas, exposed to the impact of metal stream, the effect of erosion occurs. The mould areas where material faults are present are particularly susceptible to erosion. Additionally, the high temperature of the liquid alloy (between 680°C and 710°C) affects the mould. To maintain the temperature of mould within the operational temperature, it is cooled with water flowing through cooling channels.

As the casting is removed from the mould, the mould’s inner surface is sprayed with emulsion that prevents casting adherence. Because the emulsion is based on water, the moment it comes into contact with the mould, the sub-surface areas of mould material are rapidly cooled. As an effect, stretching stresses in these areas arise. The moment liquid alloy is introduced to the mould cavity, these areas heat rapidly, which creates conditions for pressing stresses. Such cyclic changes of stresses in the sub-surface area create conditions for material degradation due to thermal fatigue.

As an effect of the water soluble coat, local mould corrosion may appear. Areas most susceptible to corrosion are those with micro cracks, micro porosity and gaps.

As a result of the molten metal influence, intermetallic phases may appear in the sub-surface areas of the mould which increase susceptibility to aluminum build-ups. This makes the castings adhere more often to the mould and require frequent removing of build-ups. During improper removal of accretions the mould inner surface may be damaged. The above factors influence devastation of the mould cavity inner surface.
Increase of the mould life-span is an important matter especially when it is kept in mind that the cost of such increase equals approx. 10% of casting production costs. Pressure castings require a high smoothness of surface. The quality of the mould surface is decisive for the casting surface smoothness. Thus, the form smoothness must guarantee no tendency of casting metal adherence, low susceptibility to erosion due to the high flow rate of liquid alloy, as well as its resistance to corrosion.

3. Materials for pressure moulds

In order to ensure a long life-span of a pressure mould, the steel used in its production must be characteristic of good plasticity (ductility), high yield point at hot temperatures, as well as resistance to tempering and a good thermal conductivity. It also must have a low thermal expansion coefficient.

The parameters influencing plasticity are mainly: cleanness from non-metallic inclusions, lack of primary carbides, strips of secondary carbides and microsegregation. The size of grain and type of microstructure, i.e. the presence of bainite or martensite, is of lower importance. The following H13 steels are characteristic of good plasticity and ductility, according to ASTM (1.23.44): ORVAR SUPREME (Premium H13), VIDAR SUPREME (Premium H11) of UDDEHOLM TOOLING AB, steel A.R.C. 3 of AUBERT & DUVAL, as well as WCLV grade steel.

Because the cost of mould production is high, in many foundries they only undergo heat treatment (heat improvement) and black oxidation. The surface of the mould prepared in this way is susceptible to aluminium diffusion from the molten liquid alloy. Because of this process, intermetallic phases are created in the sub-surface layer of the mould. The tendency for creation of inter-metallic phases has been defined by various researchers as between 7 and 150 \( \mu \text{m} \) [13-16]. The differences are explained with various temperatures of pouring, numbers of pouring or the chemical constitution of alloy. These factors may intensify or moderate the occurrence and growing of these phases. In the areas where inter-metallic phases deposit, there is an increased tendency of casting material to adhere (flash lands appear at the inter-metallic phase – cast alloy \( \alpha \) phase). At removing the casting from the mould, the flash lands are broken. As this process repeats many times, the mould material is torn out in micro zones. Research reveals [15] that in the case of moulds with surfaces not hardened the first symptoms of casting adherence to the mould may appear as early as after 500 injections. This is also true in the case of the Pressure Foundry META-ZEL.

The research team of Pressure Foundry META-ZEL conducted tests of the content of materials used for pressure moulds. The tests were made on samples provided by selected manufacturers from Poland and Western Europe and they revealed the presence of inclusions and porosity (Fig. 1). This signifies the fact that despite the sophisticated technology in steel manufacturing there is still a risk that microzones appearing near the mould cavity surface could be particularly susceptible to erosion damages and create areas of increased tendency to adherence.

4. Hardening moulds by nitriding

Steels for hot operation are characteristic of good susceptibility to nitriding which is an effect of their chemical constitution. The process of pressure mould nitriding improves their thermal endurance as well as erosion interaction of liquid alloy. Due to the high temperature of the nitriding process, approx. 500 °C, moulds maintain a high hardness of the core, obtained after quenching and tempering followed by the nitriding process. This treatment may cause slight dimensional changes, within the dimensional tolerance of the element. Thus, it may be used for ready-made elements, providing only allowances for polishing.

For the pressure mould, the research team of Pressure Foundry META-ZEL selected nitriding parameters for steel WCLV [15].

Due to the significant chromium content in the steel, very durable oxides appear on the surface of elements made of it. They are difficult to reduce in the initial phase of nitriding and they hinder creation of the nitride layer. On account of the above, before the nitriding process, the detail surface must be cleaned, for instance by sand blasting or chemical methods of surface activation (phosphatizing).

The mould nitriding process at the first stage (450 °C) and during heating for the second stage (520 °C) should be conducted in an atmosphere containing 60% \( \text{NH}_3 \). At the second stage of the
process (520 °C) the nitrogen content in the exhaust atmosphere should be limited to 25%. The time of soaking in 450 °C should be two hours. The time of soaking at the second stage should be ten hours. Then, the furnace charge, together with the furnace, should be cooled down to the ambient temperature. The ammonia content in the exhaust atmosphere should be checked every 1.5 hours with a dissociometer.

Surfaces of nitride treated elements should be of a uniform light grey colour, with slight gloss. It indicates that a nitride treated layer has been formed, with a thin zone of ferric nitrides. Clear metallic glitter indicates that the process was defective and the nitride layer is too thin (20-50 μm). The reason may be that the surface was not activated or a poor nitriding atmosphere was used.

Thickness of the nitride treated layer assessed on metallographic polished sections of control samples should equal between 100 and 200 μm. A uniform dark etching zone should be visible on the etched polished section. Closed ferric nitride networks must not appear at the borders of initial grains in the nitride treated layer. They increase the layer brittleness. Hardness measured at the sample surface should be approx. 70 HRC (1000-1150 HV5). A hardness of approx. 63-66 HRC (770-860 HV5) indicates that the nitride layer is too thin (20-50 μm). Results of the hardness measurement should be confirmed with metallographic tests on the control sample.

5. Hardening moulds by coating

In 1975, in Japan, a patent was obtained for titanium nitride (TiN) coating applied with the vacuum evaporation technique. However, a few years passed before the tools coated with titanium nitride were approved by users. Then the technology was developed by numerous companies (Balzers and others).

As a result of tests conducted by Balzers [15], it was revealed that obtaining titanium nitride in the surface layer of a pressure mould may increase the thermal endurance of the mould in the case of the short-term influence of high temperature thanks to the titanium nitride’s good tribological properties and its thermal conductivity coefficient a few times lower than that of steel. Despite intensive works on the problem of creating anti-erosion coatings on pressure moulds and of their usable properties [17-26], there are still many problems to solve. For example, if EDM is used, fusions of the surface appear, which hinders the coating adhesion. In the case of mould nitriding, the process should be conducted in order to avoid the creation of Fe₃N or Fe₂N ferric phases as the nitride treated surface containing ferric nitrides has poor adhesion to the coating. Thus, the layer must be removed before the coating application.

Works on obtaining the most favourable coating are conducted by many research centers. They focus on coating structure variations. Few studies give results of tests on the mould usable properties [15].

The TENIFER coating is achieved as a result of nitride-carburising in a salt bath. Its life-span is evaluated as 40,000 injections. The coating ensures very small adhesion of a casting. It also prevents creation of intermetallic phases. A drawback of this coating is its susceptibility to cracking.

BALINIT A is a TiN coating obtained with the PVD method. Its life-span is evaluated as 100,000 injections. The coating guarantees that castings will not adhere. It also prevents creation of intermetallic phases. It also has very little susceptibility to cracking or scaling.

The DUPEX coating is obtained with nitriding followed by an application of CrNi coating with the PVD method. Such coating has not given any significant improvement of the mould life-span.

A TiN coating, made with the CVD method, has allowed for 170,000 injections.

A coating with the use of the TD Process is obtained as an effect of vanadium and carbon diffusion in a bath. Its life-span is evaluated as 125,000 injections. Such coating ensures no adherence of casting and very little susceptibility to cracking or scaling.

According to [17], TENIFER ensures a pressure mould life-span between 7,500 and 12,500 injections. The TiN coating ensures a mould life-span between 15,000 and 45,000 injections while the Ti(C,N) coating between 20,000 and 50,000 injections. The Ti(B,N) ensures a shorter life-span, between 12,500 and over 22,500 injections, while the (Ti,Al)(C,N) coating between 22,500 and 27,500 injections.

The Research Found of Trade and Industry founded comparative testing [18] of life-spans of selected pressure mould coatings which revealed that a mould with the TENIFER coating ensured 10,000 pours, a mould with the MICROPULS-Plasma coating (a nitride treated layer + a TiN layer) ensured 30,000 pours while a mould with the MICROPULS-Plasma coating (a nitride treated layer + a TiC layer) ensured 35,000 pours.

It was found that the TENIFER coating gives a comparatively thick protective layer that is an effect of nitriding and carburising. It hinders creation of an intermetallic layer. Although the TD Process, CVD TiN and PVD TiN, as well as MICROPULS-Plasma are a few micrometers thick, they create a very compact layer that prevents the creation of an intermetallic layer.

Because these processes are conducted at different temperatures, their effect on the core hardness must be taken into account. The TENIFER treatment does not result in a decrease in core hardness. The hardness at 20 μm under the surface was 1164 HV. The TD Process is conducted at 850 °C. The CVD TiN process is conducted at 800 °C while the PVD TiN process is conducted at 550 °C. As an effect, the hardness measured at 20 μm from the material surface of the mould coated in the TD Process was approx. 495 HV while the material hardness of the mould coated in the CVD TiN process was 505 HV. Coatings obtained maintaining a high temperature, i.e. with the use of the TD Process and CVD TiN are not very susceptible to scaling as their fastening to the mould material took place as a result of diffusion. However, the use of high temperature during the process may cause mould deformation, which is a significant constraint in the case of moulds with a complex shape of cavity. As the mould was used, the TENIFER coating was observed with a significant growth of cracking, while the TD Process coating gradually became thinner.

An economic analysis revealed that the costs of TENIFER treatment are lower than those of the TD Process, PVD TiN or CVD TiN but the life-span of the mould is shorter. On account of
the economic benefits, the following ranking of treatment may be suggested as far as the highest cost-effectiveness of the coating is concerned: TD Process, PVD TiN, CVD TiN and TENIFER.

All the time, world specialist companies offer many new coatings, such as TiBN + TiB₂, TiN, TiCN, TiAlN [27-29]. These coatings are shaped on the mould material that has undergone quenching and tempering as well as nitriding (Fig. 2). Those foundries that have tried to use these coatings refuse to inform about the durability of their moulds. The factories manufacturing pressure moulds are not very interested in the use of coatings as they are afraid of prolonging the mould life-span and therefore decrease demand for new moulds.

Fig. 2. Structure of a new generation coating for pressure moulds.

References

[31] Prospekty informacyjne firmy Oerlikon Balzers.