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PREVENTING THE REJECTION OF LIGHT ALLOY WHEELS BY «TURNING OF OXIDE SPOT» DEFECT DURING LOW-PRESSURE DIE CASTING

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ABSTRACT

The occurrence of defects and the degree of incidence of cast during production of light alloy wheels by the method of low-pressure die casting depends on a large number of factors. One of the most frequent and difficult to detect (without destructive testing) defects is the turning of oxide spot. Its causes may include a wide range of variations in the composition of the raw materials, technology of alloy preparation and casting conditions. The negative impact on the product quality increasing amount of defective goods and economic losses. Solution to the problem is to use a special release coating with prescribed physicochemical properties. An experiment with coatings was carried out under production conditions, the cast weight - 12.5 kg.

Keywords: light alloy wheel, defect, oxide spot, low-pressure die casting, coating.

INTRODUCTION

Automotive wheel is an indispensable element of the vehicle platform. Installed on the hub assembly with the tire, it acts as an energy converter of the engine to the useful work of moving on the road surface (Figure-1). The mass and geometrical parameters of the wheel can significantly affect smooth ride of the car, level of vibrations, stability of movement, durability of the suspension parts.

In most cases, the wheel is operated in conditions other than stationary rolling on a flat surface, as a result of which it is exposed to constantly changing forces and moments. However, the wheel must take cyclic (acting from the vehicle) and stochastic (shock) loads without disturbing the carrying capacity, i.e. the appearance of cracks or leakage. The main loads of the cast, forged and modular wheels of passenger cars are caused by the vertical force Fz and lateral Fy (Figure-2), while the circumferential forces arising during acceleration and braking are more significant for the spoke wheels of motorcycles and limousines [1, 2].

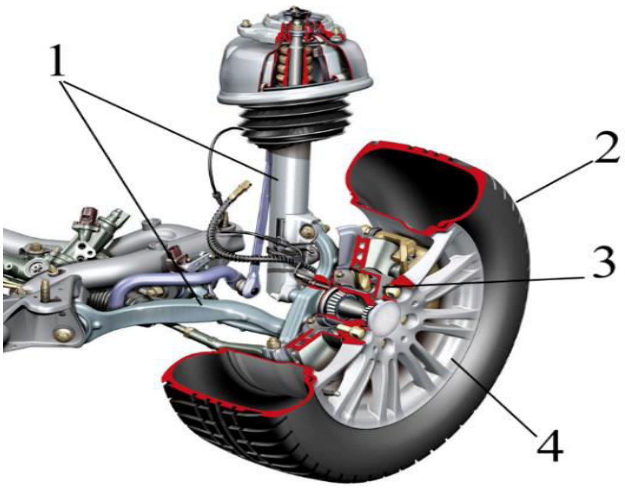

Figure-1. Wheel assembly: 1 - suspension parts, 2 - tire, 3 - hub, 4 - light allot wheel.

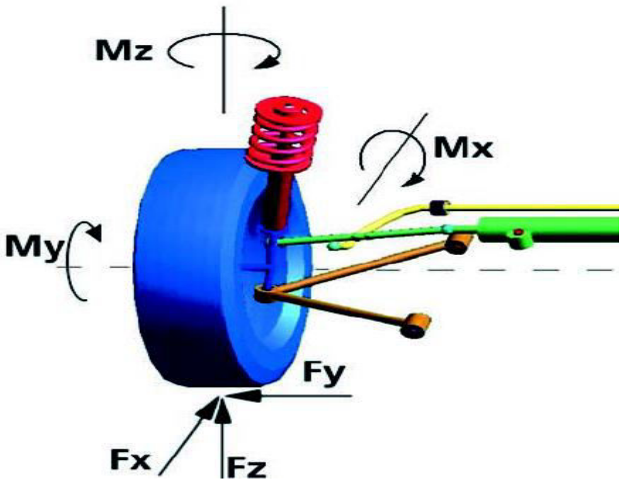

Figure-2. Forces and moments acting on the wheel during operation [2].

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It should be noted that at present the most common automotive wheels made of aluminum alloys. Due to the lower mass compared to steel, alloy wheels help reduce the amplitude of oscillations of forces in the contact patch with the road surface. The smaller inertia moment of the wheel reduces the load on transmission, which improves the acceleration dynamics and stability of vehicle [3].

At the same time, more than 80% of aluminum wheels in the world are manufactured by low-pressure die casting (LPDC), which ensures high precision of castings, wide possibilities for automation and mechanization of operations, as well as the possibility of using recycling technologies. In the production of new products can be involved not only the defective goods the technological process, but also a wheel that has completely exhausted its resource, which increases the environmental friendliness of the products.

On the other hand, this method of casting has disadvantages that can entail not only a decrease in production efficiency, but also a massive defect: the difficulty of controlling the melt flow rate in a mold; the ability to change the properties of alloy during its long exposure in the furnace of casting machine; reducing the resistance of mold material in violation of their preparation technology [4, 5].

Typical defects of LPDC

The appearance of a particular type of defect and the damage degree of cast depends on a large number of factors related to the temperature of the melt and the mold; melt flow rate, the pressure of metal during the filling of the chamber; mold material and the method of its preparation (Figure-3) [6].

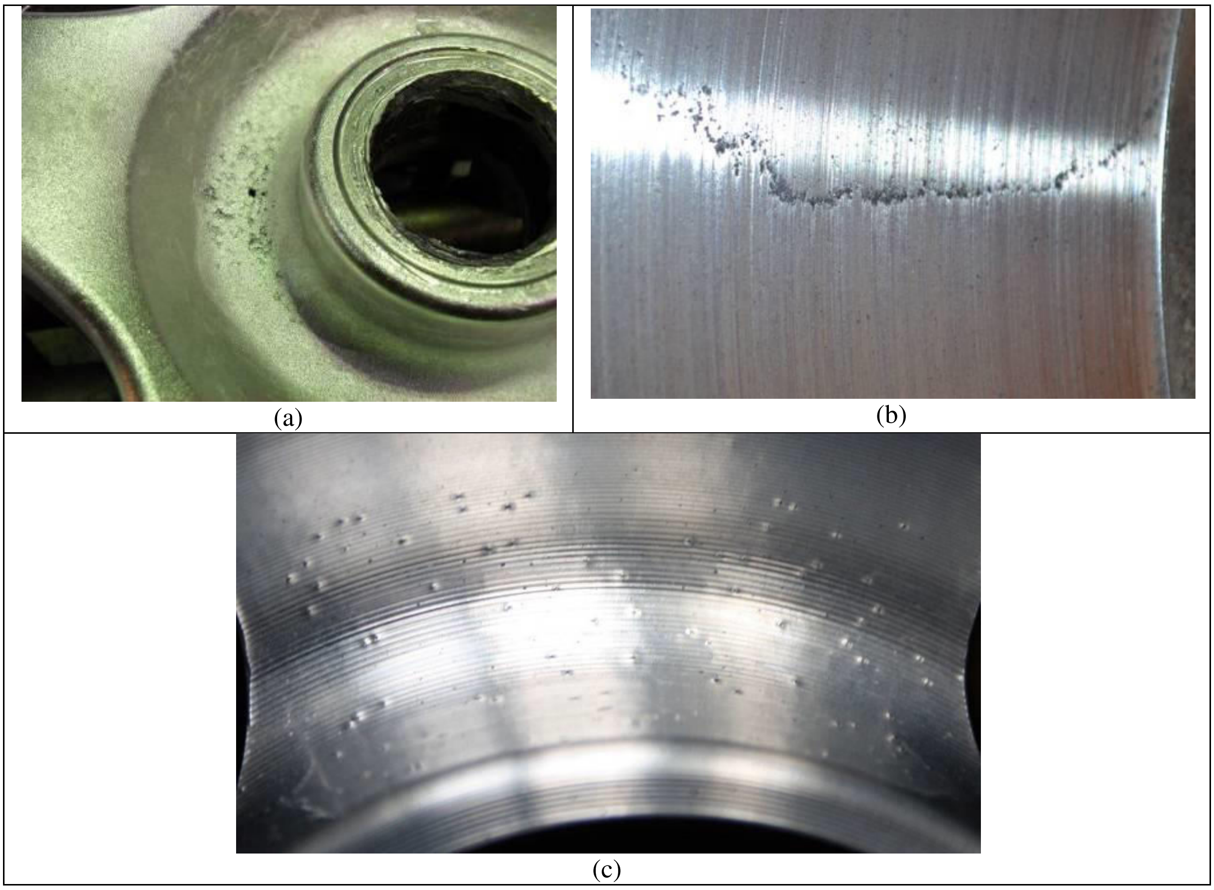

Figure-3. Defects of light alloy wheel [6]: *a* - shrink cavity, *b* - crack, *c* - porosity.

Significantly reduce the risk of many defects can be at the stage of developing new wheel models using specialized automated calculation systems. Modern studies demonstrate examples of calculating the thermal and hydrodynamic modes of casting to establish the optimal time for filling the mold with metal, identifying super cooled and overheated zones [7-10]; simulation of operational loads on the virtual model [11-13]. To carry out such calculations, are used data of chemical composition and properties of the alloy, the characteristics of mold material, the geometric model of cast with equipment, the modes of LPDC, the loading parameters.

Under real production conditions, deviations in the composition of raw materials, alloy preparation technology and casting modes inevitably occur, which lead to the appearance of metallurgical defects in products. The following groups are distinguished among the main casting defects [14-16]:

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- fillings (cold lap, splashes, oxide spot or films);
- undesirable phases (inclusions, structures, bloom);
- shrinkage (macro-shrinkage, interdendritic shrinkage, cavity);
- gas (porosity, bubble);
- thermal (cold and hot cracks);
- caused by the state of mold (roughness, scoring, welding of cast, traces of metal flow);
- geometric (under filling, breaking, deformation, traces of pushers).

Nevertheless, even taking into account the X-ray control of products and the use of appropriate software, some metallurgical defects can be detected only at finishing operations, which leads to increase amount of defective goods and economic losses [17].

A striking example of such defect is the so-called «turning of oxide spot», which is an oxide layer formed during turbulent filling of the working cavity of the mold in absence of directed crystallization of cast. Such layer is formed at the time of melt contact with the mold surface. The turning of oxide spot on the surface of cast entails the formation of unacceptable defects in finished products, such as peeling of the decorative protective coating, violation of the leak resistance. The depth of the defect from surface into the body can be from a few microns to several millimeters, such defects weaken the design of the wheel, because serve as concentrators for the initiation of fatigue cracks, causing the destruction during operation or bench testing (Figure-4).

One of the main solutions to the problem of optimal filling of the mold is use of special coatings with prescribed physicochemical properties. The separation layer of the coating on forming surface (Figure-5) allows regulating the heat transfer between melt and mold, thereby contributing to the creation of directional solidification front. It also prevents the contact of metal with mold material, which reduces the negative impact of thermal and hydrodynamic shocks, reduces the risk of formation and growth of cracks, increases the service life of mold [10].

Figure-4. Cluster of oxide spots on the outer surface of cast.

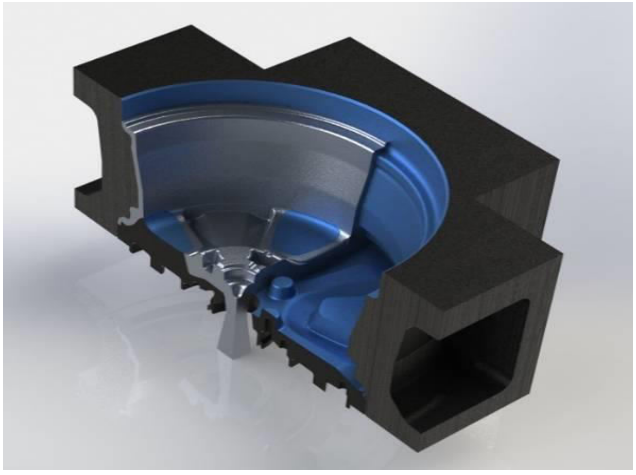

Figure-5. 3D-model of LPDC tooling with cast and special coating [10].

To ensure the constancy of the technological process and to obtain high-quality castings, used coatings of the molds must have a desired level of properties.

RESEARCH METHODOLOGY

Step 1: evaluation of the coatings applicability. Common, working and technological properties of the developed coatings were determined according to GOST 10772–78. Data on the gas creation of coatings was obtained using differential thermal analysis and measuring the relative optical density of gases released during heating. The values of the thermophysical characteristics of the coatings are set by the laser flash method on the NETZSCH LFA 457 Micro Flash equipment.

Step 2: casting under production conditions and testing. The working surfaces of the molds were painted with developed coatings using a spray gun. The composition of the raw materials, melt preparation technology and casting modes did not differ from the usual batch process. Wheel castings were obtained on the same casting machine; after which they were subjected to X-ray control.

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The wheels manufactured during the experiment were subjected to bench tests for fatigue resistance under bending with rotation, fatigue under dynamic radial load and impact at an angle of 13° (Figure-6). The loads realized at the same time are averaged in relation to the operational ones. Test conditions are contained in the relevant regulatory documents [18-22].

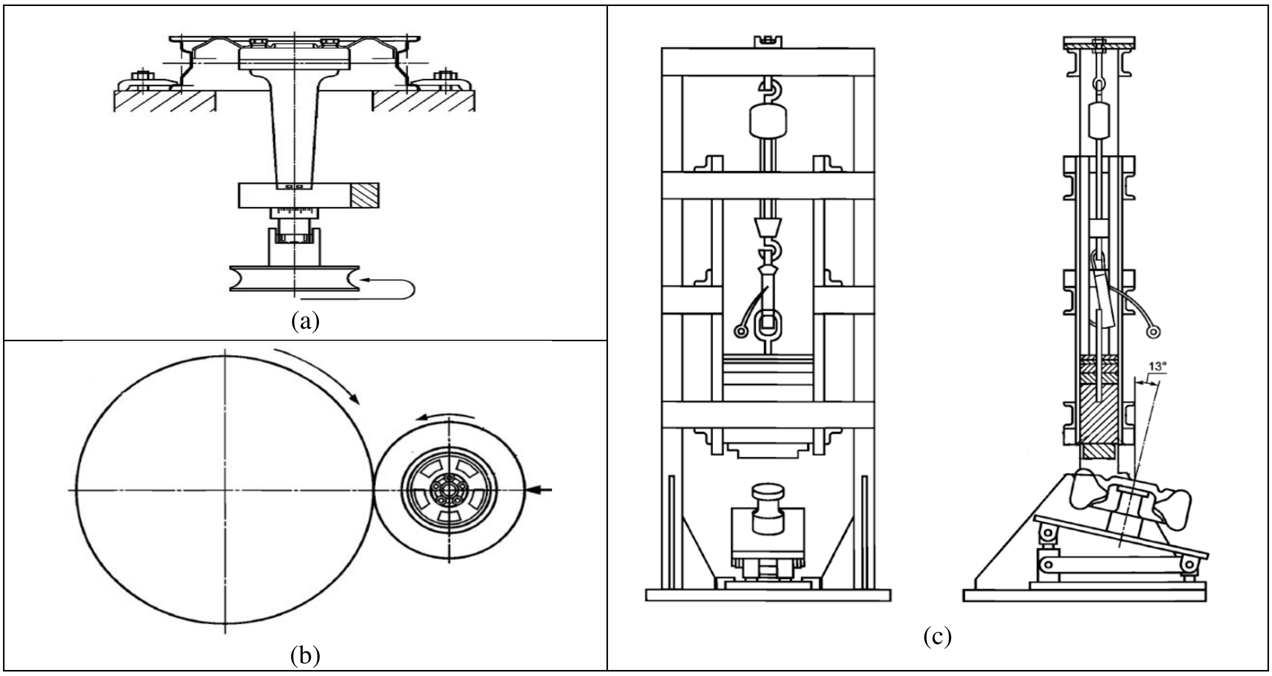

Figure-6. Schemes of equipment for bench tests [20]: a - bending with rotation, b - dynamic radial load, c - impact at an angle of 13

Step 3: destructive testing. After bench testing, a metallographic analysis was performed on samples cut from areas with visible cracks. Investigated the nature of cracks and their causes, the depth of the distribution of defects in the body of wheel.

RESULT AND DISCUSSIONS

Step 1. As a result of laboratory studies of heat-conducting and heat-insulating coatings of molds. data of their properties were obtained (Table-1).

The composition of KPT110 when applied gives a denser, uniform structure of the layer on the substrate, which corresponds to its high resistance (equivalent strength). Coarse particles of different hardness, which are included in the developed filler, ensure the formation of a rough surface, the sharp protrusions of which tighten the oxide spots to the edges of the metal flow, overcoming the painted part of mold, thereby cleaning it.

At the same time, the composition of Zh163 has a structure formed by large filler particles, the gaps between which are filled with a smaller fraction and a liquid-glass binder. Such a frame structure characteristic of heat-insulating materials contributes to the uniform distribution of fine porosity over the layer without the formation of noticeable discontinuities.

Creating favorable conditions for the formation of cast in the process of LPDC depends on the tendency of the coating to the creation of gases. Since the filling of the working cavity with the melt takes place in a short time at a temperature of about 710 °C, only a small part of the total gas creation of the coating affects gas mode of mold.

Table-1. Comparison of the properties of release coatings [10].

Properties	**Coatings**	
Description	**Heat-conducting**	**Heat-insulating**
	KPT110	**Zh163**
Binder content, %	55	60
Dilute ratio	5:1	3:1
Density, kg/m^3	1 080	1 110
Viscosity, s	10,4	11
Sedimentation stability, % after: 1 h 7 h 24 h	72 12 11	47 38 35
Equivalent strength, kg/mm	40,29	129,08
Roughness, um	3,77	9,65
Gas creation	0,001	0,03
Heat conduction coefficient at 710 °C, W/(m·K)	0,588	0,163

Step 2. Experiment with the release coating was carried out in production conditions during casting wheels: size 8Jx18, cast weight - 12.5 kg. The results of bench tests are presented in Table-2.

Table-2. Results of bench tests.

Test	Production conditions	
	Mold without coating	**Mold with coating**
Fatigue resistance under bending with rotation	NOK	OK
Fatigue under dynamic radial load	OK	OK
Impact at an angle of 13°	OK	OK

The wheel, produced without the use of special release coatings, has been unsatisfactorily tested - cracking has occurred (Figure-7). As is known, cracks are caused by the accumulation of fatigue damage, latent defects and the effect of shock loads. When tested on a bend with rotation, the wheel can be considered a transfer system, the input value of which is the load, and the reaction is the amount of deformation and the corresponding number of loading cycles until cracks appear or the wheel is completely destroyed.

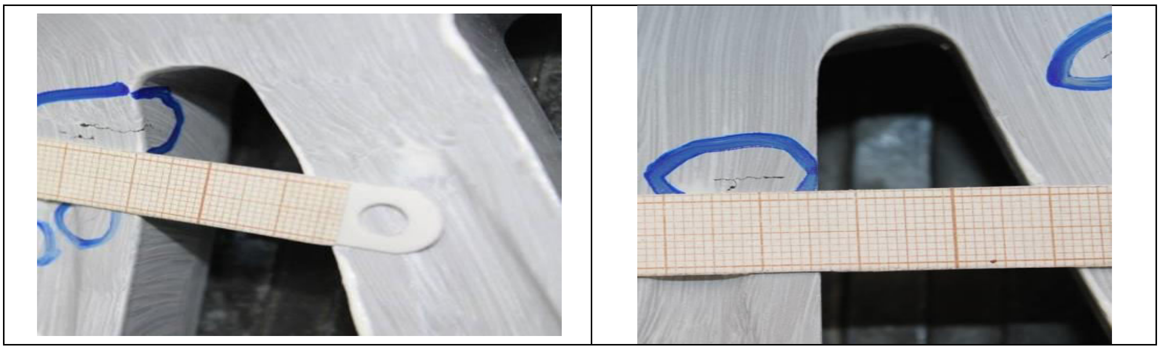

Figure-7. View of cracks after test.

Step 3. Metallographic studies of samples showed the presence of turning oxide spots from the surface in potential formation areas of cracks - along the inner surface of the wheel. It confirmed the presence of many oxide inclusions on the surface of wheel in the transition zone spokes in hub. The formation and development of fatigue cracks occurs on oxide spots from the surface of product. Deep cracks ending in the body of wheel was 5.1 mm (Figure-8).

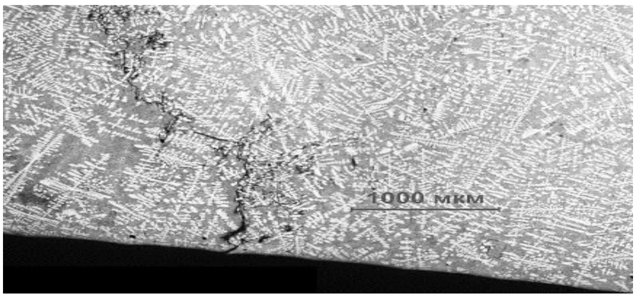

Figure-8. Microstructure of crack.

At the same time, the macrostructure of the wheel, manufactured with the use of special release coatings, indicates the absence of defects in the form of oxide inclusions on the surface of wheel in potential areas of their formation. From this it follows that the formation of the surface of cast took place under conditions of directional crystallization, established by a coating and with laminar filling of the working cavity of mold. The wheels successfully passed bench tests.

CONCLUSIONS

Growing competition requires from manufacturers of light alloy wheels not only continuous improvement of manufacturing technology, but also a reduction in total costs. If the production chain is unchanged, it is possible to improve the process of preparing molds for casting by applying special release coatings. The coating layer, due to its thermal resistance, directly changes the heat transfer between the melt and the mold, improves its fill-out, and contributes to protection of the mold material from premature destruction.

All this can significantly reduce the risk of surface and subsurface defects of wheels. The absence of internal defects, in turn, is a key to operational reliability of wheel and safety movement.

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