ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 14
Special Issue
4/2014

7 – 12

1/4

Qualitative Assessment of the Defects in Metal Casting Prosthetic Restorations

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Received 20.11.2014; accepted in revised form 12.12.2014

Summary

Due to the frequent occurrence of casting defects in the casting process of metal prosthetic elements, studies aiming at identifying the defects and determining their probable causes were performed. The work presents the results of the examinations of the Co-Cr-Mo alloy, brand name Argeloy N.P. Special, used for prosthetic restorations. Macroscopic and microscopic observations were conducted with the use of light and scanning microscopy (SEM). Also, the results of the observations by means of a 3D scanner by GOM ATOS 3 were presented. The performed research made it possible to determine and classify casting defects such as blisters, misruns and interscrystalline cracks. It was stated that a stabilized technological process affects the elimination of the casting defect formation.

Key words: cobalt-based alloys, casting defects, dental prosthetics, 3D scanner

1. Introduction

Cobalt-based alloys are among the materials used for stomatological products. Their mechanical and corrosion resistance properties are determined by their chemical composition and structure, which depends on the type of technology and the manufacture conditions [1-3]. We can distinguish between plastic working (wrought) and casting alloys [1]. The first are produced mainly for uncemented articular endoprosthesis mandrels, also for compression anastomosis elements, tips, screws and wires. Cobalt casting alloys are used mainly in stomatology for pillar implant elements and frame prostheses as well as in orthopedics for articular prosthesis elements. The applications of these alloys involve taking advantage of the casting technology as well as the easiness in acquiring the desired shape [1, 3, 7]. Casting alloys are the classic and commonly used group of the modified Vitalium type alloys, existing with different brand names [6].

Next to a range of valuable utilitarian and technological properties of the Co-Cr-Mo/Co-Cr-Mo-W alloys, their flaw is a limited plasticity, which is seen as the main cause for the occurrence of defects (cracks) of the prosthetic elements [8]. Among the structural causes of cobalt casting alloys' fragility are such factors as microporosity of the cast, dendritic microsegregations, the presence of carbides in the alloy or the cast's tendency for a coarse-grained structure [9]. However, despite their flaws, these alloys characterize in high corrosion resistance, owing to the formation of a protective oxide layer (CrO) on their surface [2, 3, 6]. An exception is local corrosion, and more precisely, crevice and pitting corrosion as well as stress and fatigue corrosion. A properly selected chemical composition and a carefully conducted production process can help minimize the corrosion risk [7, 10-12].

Metal prosthetic elements (crowns, brackets, frame prostheses, bridges, valves) based on the Co-Cr-Mo-W alloys can be produced by various methods, such as powder metallurgy, hot forging or lost wax (investment) casting [1, 2, 4]. Due to the small cross-sections of prosthetic restorations, and thus the necessity of high geometrical precision of the manufactured element, the most frequently used method in a prosthetics laboratory is the lost wax casting method, which assures the production of casts of the shape and anatomical parameters dedicated to the needs of the individual patient. The technology of the cast production with the use of the centrifugal force is difficult and it is determined by many different factors [13]. The end quality of the cast significantly depends on the technological parameters of the production process. In order for the cast to be high quality, each stage of the process should be stabilized [14].

The occurrence of casting defects cannot be entirely eliminated. This is caused by the necessity of regulating very many factors of the production process, which often cannot be controlled at the same time [15-17].

It is assumed that the defects revealed in the as-cast condition can include 2-4% of the manufactured products. This percentage is increased when more defects are revealed during the further production processes. It is generally assumed that the acceptable amount of defected casts constitutes 6% of the whole production. It should be remembered that each defect raises the production costs. The later the technological defects are revealed in the production process, the higher the losses [18, 19]. From the studies of macro- and microscopic defects of casting metallic prostheses conducted by Hajduga and Kosiba [19] we can infer that an improper control of the production process is a significant cause of the occurrence of casting defects. A flawedly-made model, an inappropriate preparation of the mould and an overheating of the metal are the most common factors generating defects in prosthetic restorations [19].

Due to the frequent occurrence of casting defects in the process of metal prosthetic element casting, studies aiming at identifying the defects and determining their probable causes were conducted.

Within the frames of this work, a macro- and microscopic analysis of ready prosthetic elements cast in a prosthetics laboratory by a dental technician was performed. Additionally, an analysis with the use of a 3D ATOS scanner by GOM was conducted.

2. Research methodology

The studies were performed on ready cast prosthetic elements (frame prostheses, clamps, substructures) made of a cobalt-based alloy, brand name Argeloy N.P. Special by Argen. The alloy's chemical composition (Table 1) and physicochemical properties data (Table 2) is given on the basis of the standards ISO 1562, ADA No. 5, FDI No. 7 and DIN 13906. This alloy is assigned for frame bracket prostheses and prostheses mounted on bolts, latches, and valves.

Table 1. The chemical composition of the investigated alloy Co-Cr-Mo, %mass.

Cr	Co	Mo	Si	Mn	C
31,5	59,5	5,0	2,0	1,0	0,4

Table 2. Physicochemical properties of the Argeloy N.P. Special alloy Argen company [20]

Melting temperature, ºC	1240-1350
Casting temperatureºC	1480
Yield strength, MPa	448
Tensile strength, MPa	166
Tensile elongation, %	9
Vickers hardness, HV10	280

Macroscopic images of the prosthetic elements were taken with the use of a Nikon T200 camera with a 60 mm macrolens, light 1:28 D.

The samples for microscopic observations were cut out of a ready prosthetic element and next submerged in a conductive resin, PolyFast, in a press, LaboPress-1. A preliminary mechanical treatment was performed, i.e. grinding on a grinding-polishing machine by Struers and with the use of abrasive papers, gradation from 800 to 4000. The final stage – polishing – was implemented with the use of disks made of diamond suspensions MDDac (1 μm diamond paste) and MDNap (¼ μm diamond paste). In order to reveal the microstructure of the examined material, the samples were chemically etched with the use of an etching reagent: 3 parts of HNO3 + 1 part of HF + 1 part of glycerin. Microstructure observations were performed by means of a light microscope LEICA DM 4000.

Observations of the casting defect details of the examined prosthetic elements were conducted also with the use of an electron scanning microscope HITACHI S-3500N. The examinations performed by means of a 3D ATOS scanner by GOM made it possible to precisely scan the prosthetic element and convert the image into the CAD software. The device makes it possible to scan a plaster model in three planes in order to design the prosthetic element with the application of the CAD/CAM technology and with the necessary treatment precision. The measurements performed by the scanner are based on the triangulation principle. The projector performs a projection of the white light striation systems on the measured object, which is recorded by two video cameras. The light shed on the surface of the object undergoes distortion. The reflected rays are accumulated by the device (scanner) and next processed by the computer software, a result of which is a three-dimensional image of the measured object. During a single measurement, lasting about one second, we obtain up to 4 000 000 points. In order to acquire a full image, one should perform from a few to a dozen of single measurements from different positions of the head in respect of the object [21-23].

3. Test results and analysis

The macroscopic observation made it possible to reveal the casting defects on the examined prosthetic elements, such as blisters, misruns and cracks. The defects formed in the prosthetic metal elements are presented in Figures 1÷3.

Fig. 1. Cast of a frame bracket prosthesis with a visible casting defect in the form of blisters

This type of casting defect is a result of the presence of a gas in the alloy during its solidification or an insufficient release of the air and gases filling the mould cavity (Fig. 1). In order to prevent the occurrence of this type of casting defects, one should assure a proper degasification and purification of the metal [24-27].

a)

b)

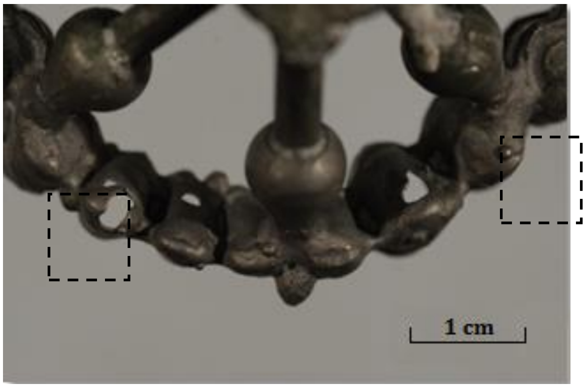

Fig. 2. Structure of a circular bridge with visible uncut feed channels (a) and casting defects in the form of blisters and misruns in the upper and side part of the substructure (b)

A misrun is a casting defect which is formed at an insufficiently high casting temperature and with an insufficient metal castability (Fig. 2). The cause of the occurrence of this type of defect is a badly-designed system of gates. In order to eliminate such defects in cast alloys, one should raise the casting temperature or implement a different design of the gating system construction [27].

Fig. 3. Frame prosthesis with a visible cold fracture on the side of the bracket

The defect presented in Figure 3 occurs in the areas undergoing stresses, that is in those sections of the cast which solidify last. In order to avoid the occurrence of this defect in the cast prosthetic element, one should apply slow cooling in the mould and carefully knock the cast out [27].

The performed microscopic observations allowed for a more precise analysis of the examined alloy.

a)

b)

Fig. 4. Microstructure of the Co-Cr-Mo alloy with a visible casting defect – intercrystalline crack: a) magnification 50x, b) magnification 100x

The microstructure revealed during the etching consists of a matrix constituted by a solid heterogeneous solution of chromium, molybdenum and carbon in β-Co matrix (Fig. 4). At the crystallite boundary and in the interdendritic spacings, we can observe the presence of dispersive carbide precipitates of a continuous character of the $M_{23}C_6$ ($Cr_{23}C_6$) or $(MoCr)_6C$ type. The basic element which undergoes segregation is chromium; molybdenum segregates to a lesser degree [2-6]. The microscopic observations revealed a defect in the form of a crack running along the dendrite axis (Fig. 4b). The most frequent cause of the occurrence of this defect is an improper course of the cast alloy solidification process [8].

The SEM observations confirmed the presence of cast defects in the form of microshrinkages and pores occurring in the dendrite arms (Fig. 5a) as well as microcracks running along the dendrite axis (Fig. 5a-c).

a) b) c)

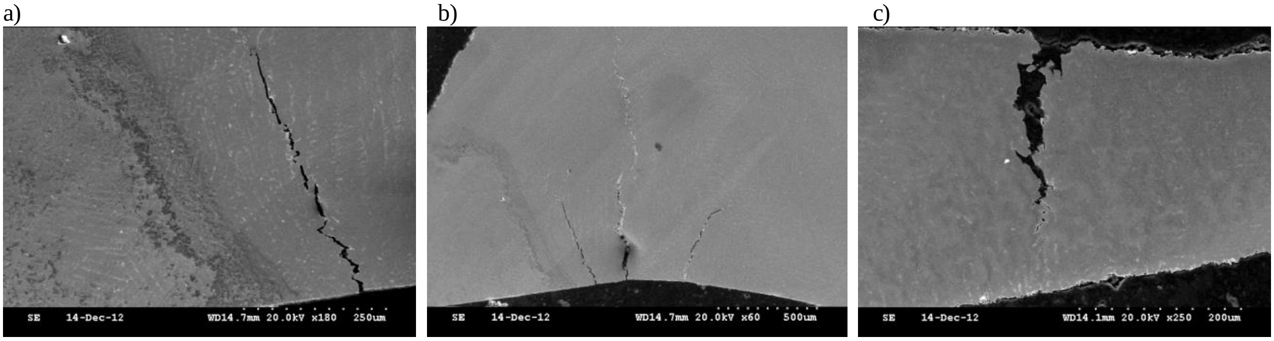

Fig. 5 Scanning images with visible casting defects in the form of microshrinkages and pores as well as cracks, with different magnifications (a), (b) and (c)

The results of the observations preformed with the use of the ATOS 3 device are presented in the illustrations (Fig. 6-9). The conducted examination made it possible to reveal the external casting defects formed in the analyzed prosthetic element.

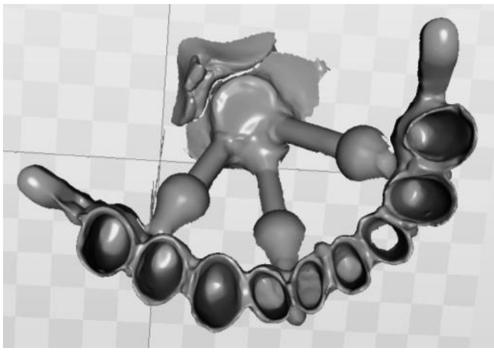

Fig. 6. Visualization with the use of a 3D ATOS scanner of a circular bridge structure with a visible casting defect (misrun)

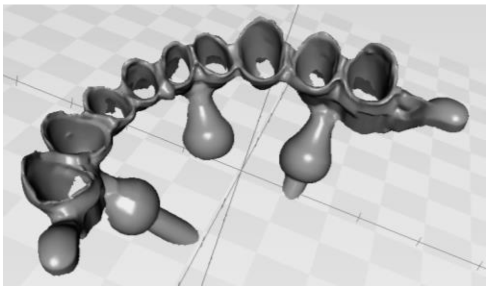

Fig. 7. Three-dimensional image of a circular bridge structure with a visible „series" of misruns revealed by means of a 3D ATOS scanner

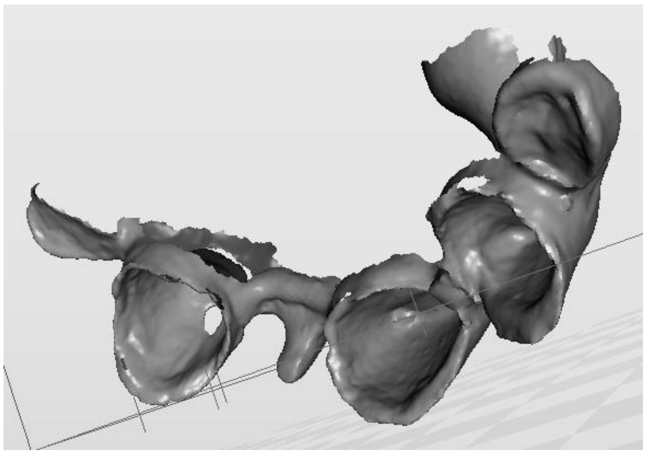

Fig. 8. 3D visualization with the use of a ATOS 3 scanner of a substructure with a casting defect (misrun)

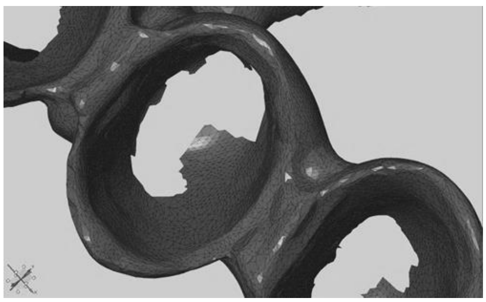

Fig. 9. 3D visualization of a triangle network showing the measured surface fragments of a circular bridge structure

The GOM technology makes it possible to process the scanned element (detail) into a digital form. This allows for a detailed observation of the elements in the three-dimensional system, owing to which we can precisely analyze the measured element in space. The GOM Inspect program made it possible to perform a virtual visualization of the measured section of the examined frame prosthesis. The conducted examinations revealed casting defects in the form of a misrun of the material (Fig. 6-9).

4. Discussion of test results

Metallic prosthetic restorations, such as frame prostheses, are precise „openwork" constructions. They characterize not only in a significant diversity of the wall thickness (from 0,6 mm) in the particular sections of the prosthetic element but also in the latter's complicated prosthetic construction process. The formation of casting defects is affected by many technological factors during the casting process of a metal prosthetic element.

The presented work aimed at reviewing and characterizing the defects formed during centrifugal casting of frame prostheses, substructures or brackets, which had been made in a prosthetics laboratory by a dental technician. The formed defects were characterized according to the Polish standard PN-85/H-83105 [24].

One of the causes of the formation of shape defects is an improperly designed gating system. A frequent cause of the occurrence of casting defects is an inappropriate location of the ingates, which generates strong perpendicular strikes of the liquid metal at the walls of the mould. That is why, in the areas where there is a risk of a mould cavity deformation, the ingates should be situated at an angle in respect of the mould cavity. An earlier solidification of the metal causes an incomplete fill-up of the mould, which results in the presence of defects such as a misrun of the material. The occurrence of a misrun is, to a large degree, caused by an insufficient castability of the metal. A defect of this type can also be caused by an insufficiently high temperature of the metal (which should be controlled throughout the whole technological process), a badly selected chemical composition or a thickness of the cast walls too low in respect of its height [26].

Another factor which affects the formation of casting defects is an inappropriate selection of the moulding materials. The investment material should be appropriately selected in respect of the melting temperature of the cast alloy. An improper selection of the moulding sand influences the external shape defects of the cast elements as well as causes gaps, discontinuities, blisters and microshrinkages inside the cast.

A cold or hot crack of the material is a result of a temperature difference in the cross section, which generates shrinkage stresses formed during the solidification process. The formation of this type of defects may also occur when the knock-out of the cast from the metal mould is too rapid or the content of gases in the metal which are formed in the alloy during its casting or during the mould filling process is too high. Too high an amount of non-metallic inclusions as well as their disadvantageous form also negatively affect the quality of the cast [26].

In the solidification process, the casting stresses present in the material generate not only external defects but also structural ones. An intercrystalline crack is the main defect of centrifugally cast materials. It is a fracture running between the grains of the alloy. Its main cause is an improper course of the metal's solidification process. Another internal defect which can be present in the cast is a blister. The main factor for the occurrence of blisters is the gas released from the moulding sand as well as the gas released from the metal during its solidification. In order to eliminate the causes of the defect, one should assure a proper degasification and purification of the metal [14, 25, 26].

To sum up, the occurrence of casting defects in the alloy is tightly connected with such factors as: an improper alloy preparation, an inappropriate preparation of the mould and an overheating of the metal. An important advantage is a casting practice supported by theoretical knowledge in the area of casting as well as materials engineering.

Acknowledgements

The work has been implemented within the framework of statutory research of AGH University of Science and Technology, contract **No 11.11.110. 299** AGH

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