Article citation info:
BEER K, PAŁKA K, SUROWSKA B, WALCZAK M. A Quality Assessment of Casting Dental Prosthesis. Elements. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2013; 15 (3): 230–236.

Karolina BEER
Krzysztof PAŁKA
Barbara SUROWSKA
Mariusz WALCZAK

A QUALITY ASSESSMENT OF CASTING DENTAL PROSTHESIS ELEMENTS

OCENA JAKOŚCIOWA ODLEWANYCH ELEMENTÓW PROTETYCZNYCH*

Properties of fixed and mobile dentures, as well as their design have a significant impact on their durability in a complex state of biomechanical loads that occur in the oral cavity during the chewing process. Elements that are usually mechanical damaged (cracking) in skeletal prostheses are metal clamps. Damage of fixation of dentures not only results in the inability to further operation, but also is causing discomfort in the patient and can lead to injury of the oral cavity, teeth and risk of complications in case of access into the digestive system.The aim of this study was to evaluate the quality of items of prostheses manufactured using available techniques and the analysis of the causes of premature loss of functional quality of these elements. Dental cobalt matrix alloy - Wironit Extra-hard was used for the study. Qualitative research consisted of the evaluation of the nature and intensity of internal casting defects and evaluation of macro-and microstructure of manufactured castings using microscopic techniques. Research of breakthroughs indicate the occurrence of casting shrinkages. Microstructural research revealed the presence of a typical dendritic structure of the matrix in form of solid solution Co-Cr-Mo and eutectic. Strength test results achieved in the relation to the macro and microstructure were also carried out. A quantitative assessment of the intensity of casting defects using image analysis was realized. Potential risks of casting technology were identified and a methodology of monitoring the state of elements of dentures was proposed.

Keywords: *durability of prosthetic devices, casting defects, cobalt alloys.*

Właściwości stosowanych uzupełnień protetycznych stałych i ruchomych oraz ich konstrukcja mają istotny wpływ na ich trwałość w warunkach złożonego stanu obciążeń biomechanicznych, jakie występują w jamie ustnej w trakcie procesu żucia. Elementami, które najczęściej ulegają uszkodzeniom mechanicznym (pękaniu) w protezach szkieletowych są metalowe klamry. Uszkodzenie mocowania protezy skutkuje nie tylko brakiem możliwości jej dalszej eksploatacji, ale również jest przyczyną uczucia dyskomfortu dla pacjenta i może powodować skaleczenia jamy ustnej, uszkodzenia zębów oraz ryzyko powikłań w przypadku przedostania się do układu pokarmowego. Celem pracy była ocena jakościowa elementów protez wytwarzanych dostępnymi technikami oraz analiza przyczyn przedwczesnej utraty funkcjonalności tych elementów. Do badań zastosowano stop stomatologiczny na osnowie kobaltu Wironit Extra-hard. Badania jakościowe polegały na ocenie rodzaju i nasilenia wewnętrznych wad odlewniczych oraz ocenie makro- i mikrostruktury wytworzonych odlewów z wykorzystaniem technik mikroskopowych. Badania przełomów wskazują na występowanie rzadzizn spowodowanych skurczem odlewniczym. Badania mikrostrukturalne wykazały obecność typowej struktury dendrytycznej z osnową w postaci roztworu stałego Co-Cr-Mo i eutektyką. Wykonano również analizę wyników badań wytrzymałościowych w powiązaniu z uzyskiwaną makro i mikrostrukturą. Dokonano oceny ilościowej nasilenia wad odlewniczych wykorzystując analizę obrazu. Wskazano potencjalne zagrożenia technologii odlewania oraz zaproponowano metodykę monitorowania stanu elementów protez.

Słowa kluczowe: *trwałość aparatów protetycznych, wady odlewnicze, stopy kobaltu .*

1. Introduction

Despite the growing popularity of implants, dental partial prosthetics are still eagerly used due to its functionality and low cost of production [1,10]. One of the types of partial dentures is skeletal denture. It is used in patients who have a too large loss of teeth and it is impossible to use a bridge reconstruction. Skeletal dentures cover the patient's toothless mouth appendages. In the case of the upperdenture also part of the palate, the lower denture – part of the sublingual area. These are periodontium supported, reduced plate prosthesis. They consist of a metal skeleton – including bonds and supporting components, metal fasteners (clamps, bolts) and the reconstructed teeth (Fig.1a). Their functionality is based on the ease of forming and individual adaptation to the anatomical characteristics of the patient while providing high mechanical strength and corrosion resistance.The metal substructure-of partial dentures are made, inter alia, froma cobalt-chromium alloys, which have a high resistance to corrosion due to the formation of the protective oxide layer on the surface [5, 11, 15].

Metal implants based on Co-Cr-Mo alloys can be manufactured by various methods, [6] inter alia, by a hot forging or by powder metallurgy, but the formation of partial dentures, because of the need to obtain a high accuracy of the geometric in case of small cross-sections, is realized by a melted models method.

This method is provide to obtain complex shape castings, fitting to the individual patient's anatomical features, in a dental laboratory. For melting alloys induction heating is used, which allows for a short time of operation, eliminates a large part of casting defects and reduces costs. The liquid alloy is cast usinga centrifugal or vacuum-pressure method. Casting with the use of centrifugal force is recommended, especially for complex shapes castings and larger in sizes,

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

a) b)

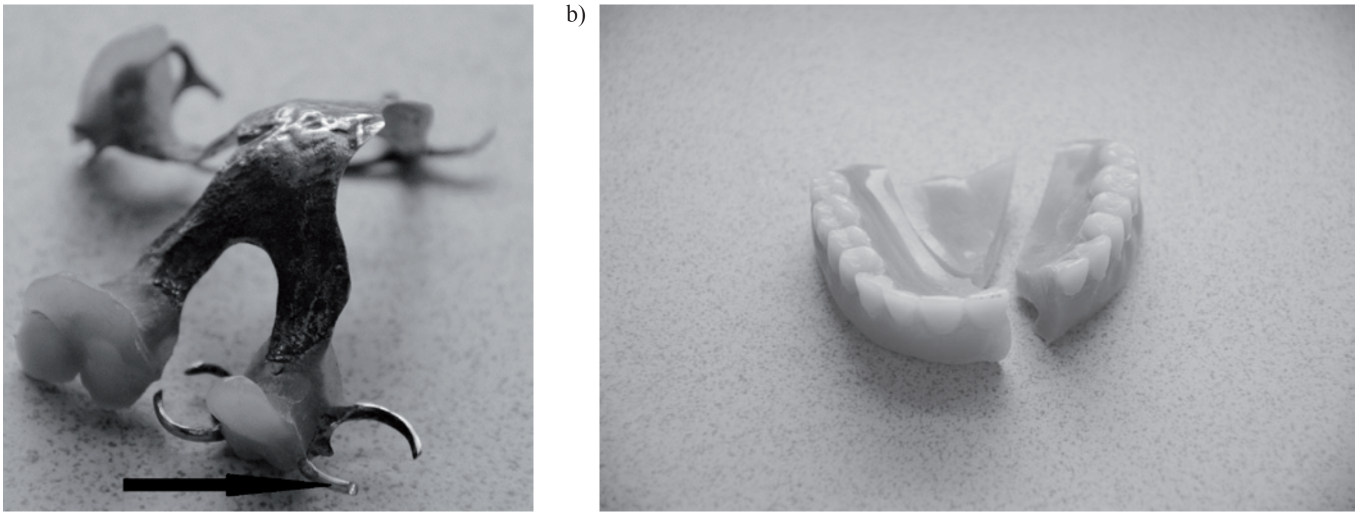

Fig. 1. a) Clamp damage of a skeletal denture, b) Failure of an acrylic denture

such as skeletons of dentures or multi-span bridges. Vacuum casting is mainly used for smaller items, such as crowns or short bridges.When the manufacturing process is properly conducted it should provide similar results of macro-and microstructure in the case of elements with small cross sections (e.g. clamps).

Properties of used fixed and mobile dentures, and their design have a significant impact on their durability in a complex state of biomechanical loads that occur in the mouth during the chewing process. The mechanical loads are responsible in the main part for the damages and failures of prosthetic supplies. Clamping forces depending on the size, intensity, duration and location cause varying degrees of stress concentration in the hard tissues of the tooth and dental restorations, which often results in damage to fasteners or damage to the entire denture prosthesis (Fig. 1a, b). There are two groups of denture failures:

- intraoral, they are mechanical, violence, diseases (eg. epilepsy);
- outside the oral cavity, can include chronic mechanical failures – wear of a prosthesis, conditions changes in prosthetic ground that cause an inaccurate adhesion of plates and uneven load, no offloads, ragged occlusion of teeth and habits – occlusion and no-occlusion parafunctions [2].

Elements that are usually mechanical damaged (cracks) are clamps. Damage to fixing dentures not only results in the inability to continue service (prosthesis no longer fulfills its function, does not carry the mechanical loads), but also cause discomfort in the patient. In addition, a damaged clamp, unnoticed by the patient, can cause a mouth injury, mechanical damages to the teeth or get into the digestive system, where a sharp foreign body is the biggest danger because of the possibility of complications.

Prostheses and their parts are a significant part of a set of sharp foreign bodies in case of adults. Weiland et al. [19] describe the 256 foreign bodies in the 10-clinical observation, and O'Sullivan et al. had conducted 308 foreign bodies observation over 4 years, of which 88.3% had accidentally ingested [14]. Velasco et al. report that in the years 1981–1989, 617 foreign bodies was endoscopically removed, 541of which from adults, the oldest adult was at the age of 98 years [16]. The Velitchkov et al. based on their own experience, from the 20-year follow-up, found 542 foreign bodies in patients aged from 15 to 82 years [17].

Favorable physico-mechanical properties of cobalt alloys and availability of the manufacture method (*Best Available Techniques*) affect the prevalence of the metal frame based prostheses and their affordable price. However, the analysis of potential dangers and their number indicate a need to recognize the problem of premature failure of prostheses, mainly clamp failures, due to the many risks of injury. Understanding the causes of premature failures and consequently, loss of performance characteristics of metal partial dentures will later develop methods to extend their reliability. The aim of the study is to assess the quality of prostheses elements manufactured using available techniques and an analysis of the causes of premature loss of function of these elements.

2. Materials and methods

The process of manufacturing of examined elements was carried out in the conditions of the professional prosthetic workshop according to the procedures used for the manufacture of partial dentures. Casting was performed using an induction centrifugal casting machine ROTOCAST (Roko Dental Equipment, Poland) and the vacuum-pressure method in the Nautilius casting machine (Bego, Germany) using the ceramic crucibles.

For the test a dental cobalt matrix alloy Wironit Extra-hard (Bego, USA) was used, with a nominal composition (by mass) 63% Co, 30% Cr, 5% Mo, 1.1% Si and Mn<1% C <1 % [20]. This alloy is used for casting partial dentures, clamp dentures and dentures mounted on bolts and fasteners. The melting point for this alloy is 1533K – 1578K, and the casting temperature is 1693K.The single casts were applied. Models of clamp of partial dentures are ready to use, identical contour masters (Fig. 2). On their base a ceramic mold was made using melted models method and aceramic pulp by Wirovest (Bego, USA) and the mold firing temperature 1273K. After removing the ceramic shell and cutting off parts of the casting gate a surface of samples was blasted using a sand spreader – ECOBLAST ESTATE 1 (Prodento-Optimed, Poland). Applying the same principle the cylindrical samples were prepared for the strength tests according to DIN EN 10002-1, with a measuring diameter ϕ 3 mm and a measuring length of 15 mm. Research methodology of mechanical properties is shown in previous publications of the authors [3, 18].

As-cast samples as well as samples after tensile tests were subjected to observation. Qualitative research consisted of the evaluation of the nature and severity of internal casting defects and evaluation of macro-and microstructure of castings using microscopic techniques. Microscopic examination was performed using a scanning electron microscope (Zeiss Ultra Plus) and a light microscope (Nikon MA200). The severity of defects is defined as the percentage of defects in the cross-section of an element using an image analysis software Image-Pro Plus (Media Cybernetics, USA), and images with a resolution of 3530×4404 pixels.

3. Results and discussion

Visual assessment, including scanning electron microscopy in range of small magnification, showed that manufactured elements had a good surface quality and a lack of defects. There has not also been observed the shape and dimensional deviations. The results of observations are given in Figure 3.

Observations of the fractures of elements made by both methods: centrifugal and vacuum pressure, point to the distinctive structure of the cast with the main direction of crystallization from the external surface of the product with the completion of the crystallization in the center of the element (Figure 3 (a) and (c)). Dendritic structure is also clearly exposed. In the central part of the elements the shrinkage porosity is observed, the details of these areas are shown in Figure 4.

Fig. 2. Ready to use a waxen contour master of prosthetic clamps

Microstructural studies showed the presence of a typical dendritic structure (fig. 5a, d) with a solid solution of Co-Cr-Mo with eutectic. Microsegregations have been observed within crystallites. Primary precipitates of continuous nature are located in the interdendritic spaces and along the borders of crystallites. Specimens made by a vacuum-pressure method are characterized by the presence of single cases of microporosity and shrinkage porosity (fig. 5b, c) whereas castings made by a centrifugal method are characterized by the presence of porosity that occurs along the axis of the dendrites (fig. 5e) and shrinkage porosity occurring in the arms and microcracks propagate between shrinkage porosity arms (fig. 5f). Similar structures are observed in the casting Co-Cr-Mo alloys with a lower carbon content [4, 7, 9, 12].

Tensile tests (Tab. 1) show that the properties of the castings made by a vacuum-pressure method are higher those made by centrifugal one. However, for both methods of casting mold filling (vacuum-pressure and centrifugal) the mechanical properties are lower than these declared by the manufacturer (R_m = 910 MPa, $R_{e0,2}$ = 625 MPa [20]). These figures and the fact that some of the fractures of the test samples have occurred outside of the measuring length (fig. 6) indicate the presence of structural defects in castings.

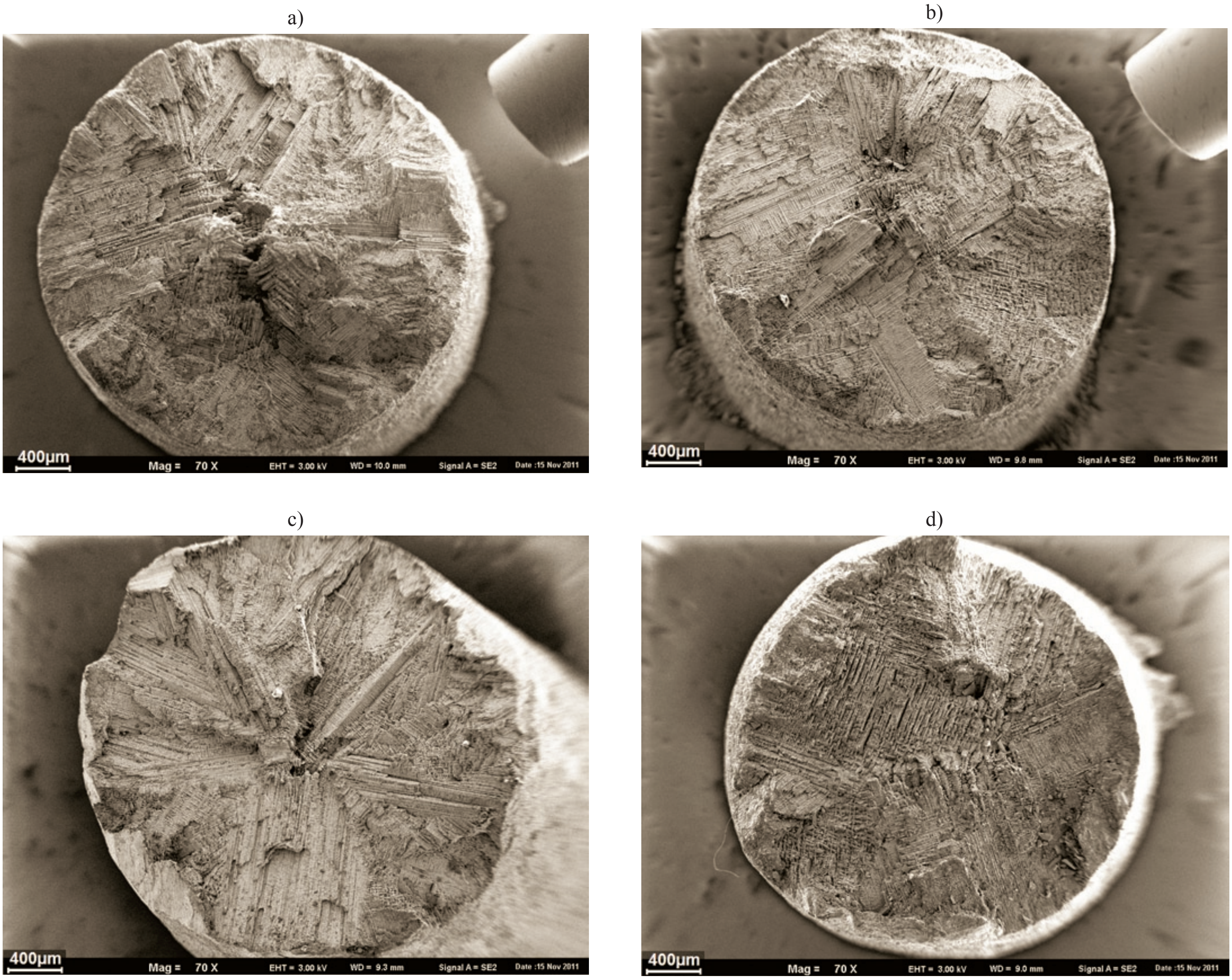

Fig. 3. Macrostructures of fractures of selected elements: a), b) - made by a vacuum pressure casting method; c), d) – made by a centrifugal casting method

a) b) c) d)

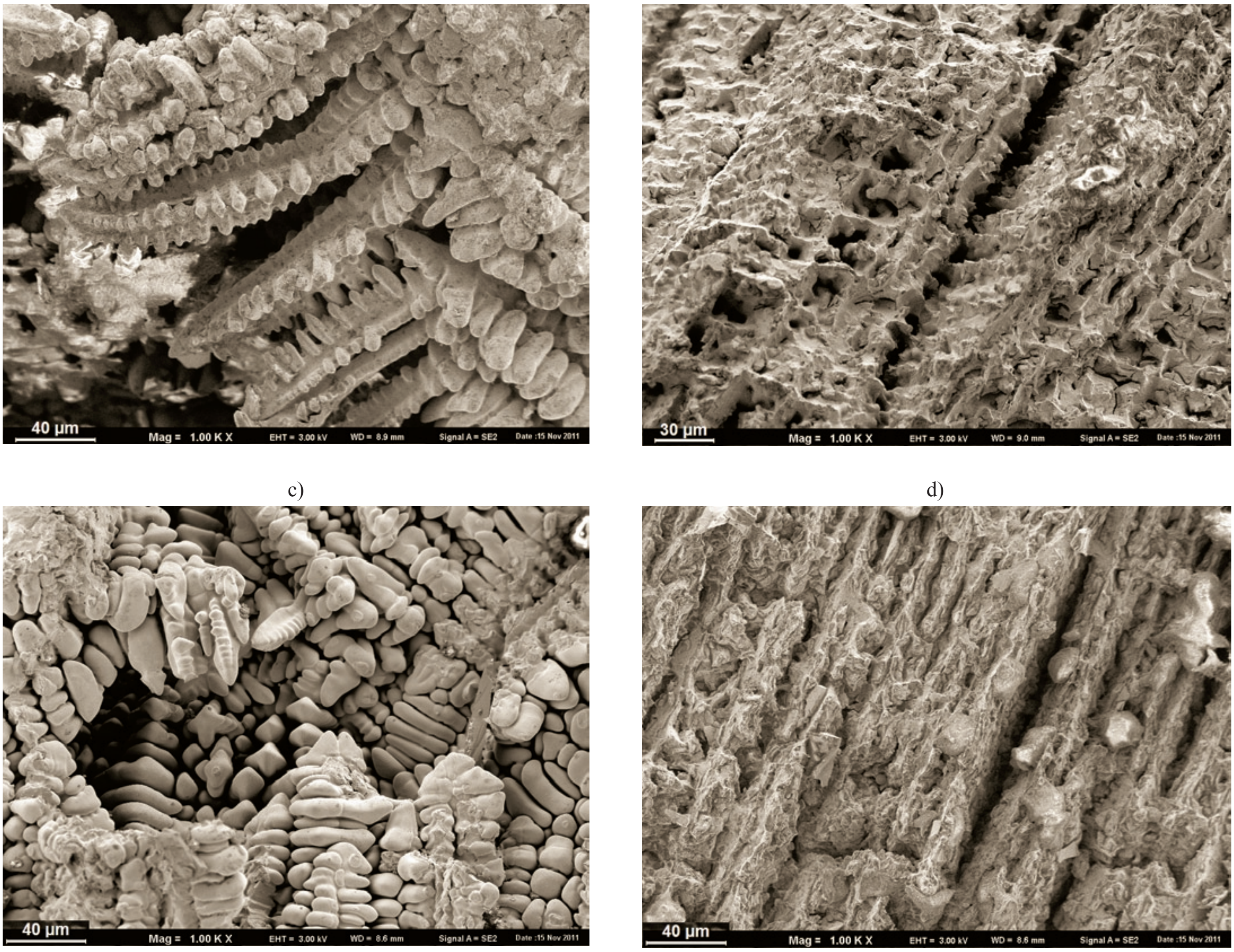

Fig. 4. Casting defects in the structure of tested elements: a),b) made by a vacuum pressure casting method: shrinkage –a) crack along the dendrite –b); c),d) made by a centrifugal casting method: shrinkage - c), shrinkage and porosity c) and d)

Strength reduction in relation to the manufacturer's data may be the result of the presence of shrinkage porosity in the structure of the cast. They reduce the cross section of the element and cause a notch effect. In addition, the arrangement of the shrinkage porosity and microcracks (in the dendritic arms, along the axis of the dendrites) prevents plastic deformation of these areas and compensation for the propagation of cracks. The relatively low plasticity of the alloy may be the source of the microcracks propagation arising between areas of shrinkage porosity, where the metal zone is not able to transmit the thermal stresses during cooling. These microcracks promote especially in eutectic areas with low plasticity and therefore low value of fracture toughness (fig. 5f).

The ratio $R_{e0,2}/R_m$ declared by the manufacturer is 0.68, while for the material obtained is 0.75 for the centrifugal and 0.72 for the vacuum-pressure method. The value of the elongation obtained is 2–3%. These results are comparable with those published in [8, 13] and testify for unsatisfactory ductility. There are some experiments taken to increase the strength and ductility by heat treatment [8, 12], except that the problem is the selection of the treatment conditions for alloys with a high carbon content (~ 1% in tested material).

Assessment of the intensity of casting defects made by image analysis (fig. 7a, b) indicates the presence of about 1.3% of pores in the element cross-section, whereas their largest concentration usually occurs in the central part. There is also a large amount of radial cracks, which in the case of fatigue loads will significantly shorten the service life by facilitating the propagation of fatigue cracks. It should be noted that the evaluation has been carried out in the cross section, while in the longitudinal section the longitudinal defects occur (fig. 7 c), significantly reduce the flexural strength and fatigue life.

Table 1. Results of tensile tests for specimens made by both casting methods

	Metoda odśrodkowa/ Centrifugal casting method[MPa]	Współczynnik zmienności /coefficient of variation [%]	Metoda próżniowo-ciśnieniowa/ Vacuum –pressure method [MPa]	Współczynnik zmienności/ coefficient of variation [%]
R_m	781	2,6	838	3,9
$R_{e0,2}$	585	2,5	601	1,1

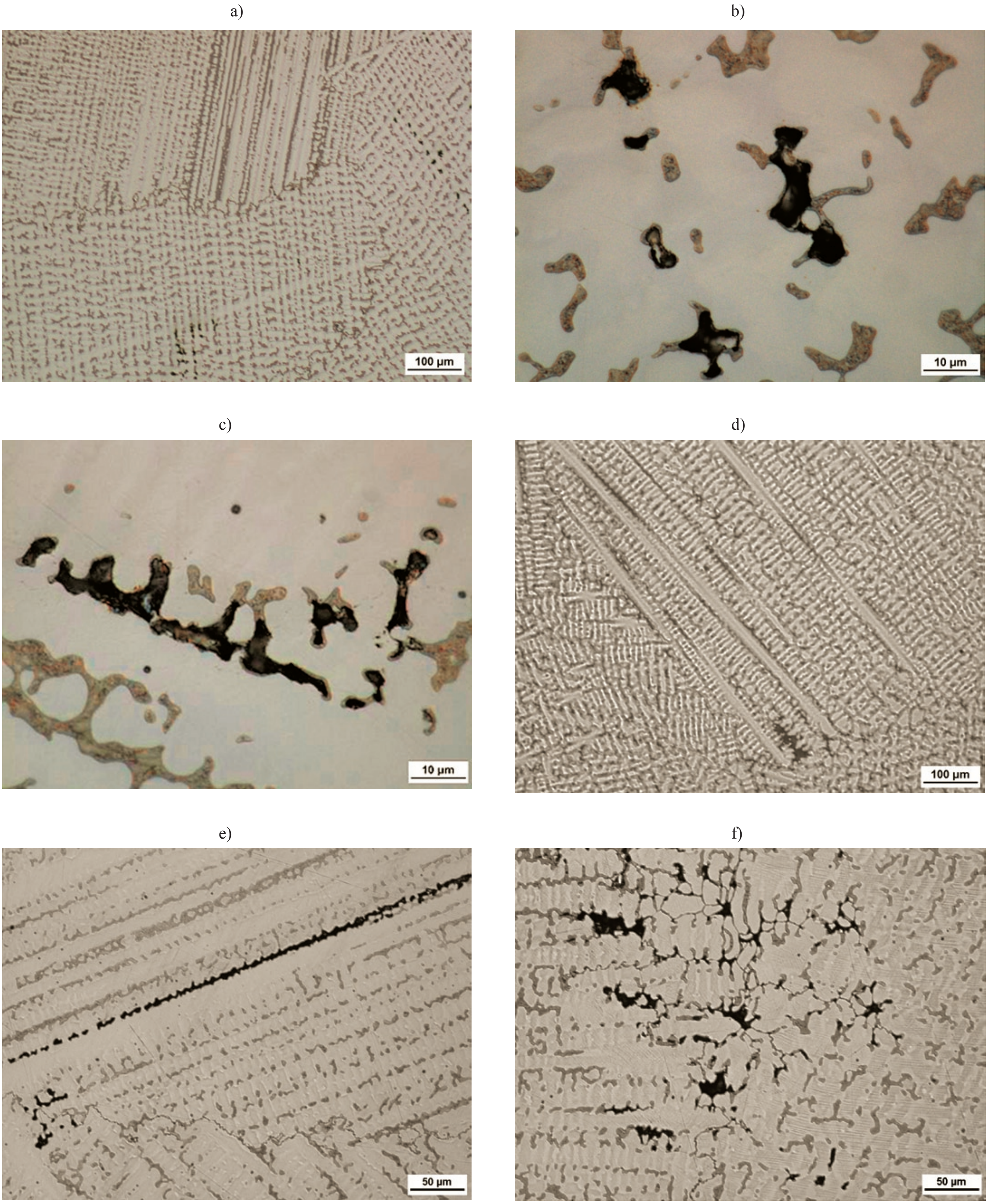

Fig. 5. A microstructure of castings a), b), c) – a structure of a Wironit extra-hard cast alloy after vacuum pressure casting, single microcracks – b), c); d), e), f) – a structure of a Wironit extra-hard cast alloy after centrifugal casting: microcrack along the dendrite axis – e), shrinkages in the dendritic arms and micro-craks propagating between shrinkage areas – f)

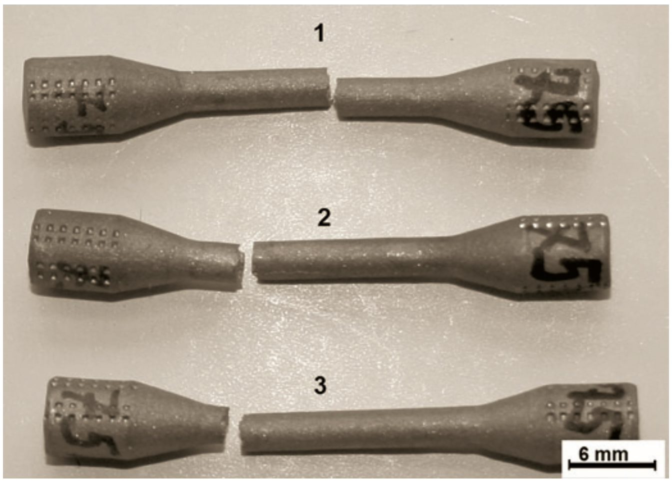

Fig. 6. Samples after a static tensile test: 1 – a fracture on the measuring length; 2, 3 – fractures out of measuring length

4. Summary

Presented studies have shown that the castings made in accordance to the procedure valid in prosthodontics laboratories are characterized by a significant amount of casting defects in the form of pores and shrinkage porosity. Microstructural studies showed the presence of a typical dendritic structure with presence of primary precipitates. Fractures are brittle and obtained mechanical properties provide low ductility. This type of structure in conjunction with casting defects is the cause of the cracking during exploitation of dentures.

Risk reduction of the occurrence of defects in casting structures and increasing of mechanical properties requires to refine the guidelines of casting technology and parameters of possible heat treatment, while maintaining an acceptable level of production costs.

In addition, in order to prevent complications that developed after damage of the dentures (damage of the teeth or choking), it is advisable to monitor the status of the denture by a visual evaluation at the time recommended by dentists (every 6 months). During such visits the doctor should assess the status of the prosthesis by sensible observation under a dentist microscope (available in a growing number of surgeries) or with the use of other optical instruments. Metal elements should be primarily subjected to assessment (for prevalence of scratch or microcracks – as the beginning of a fatigue fracture). The other neuralgic area are the edges of the dentures – also for the presence of the microcracks and any damage leading within a short period of time to fatigue failure and the loss of functionality of the prosthesis.

a)

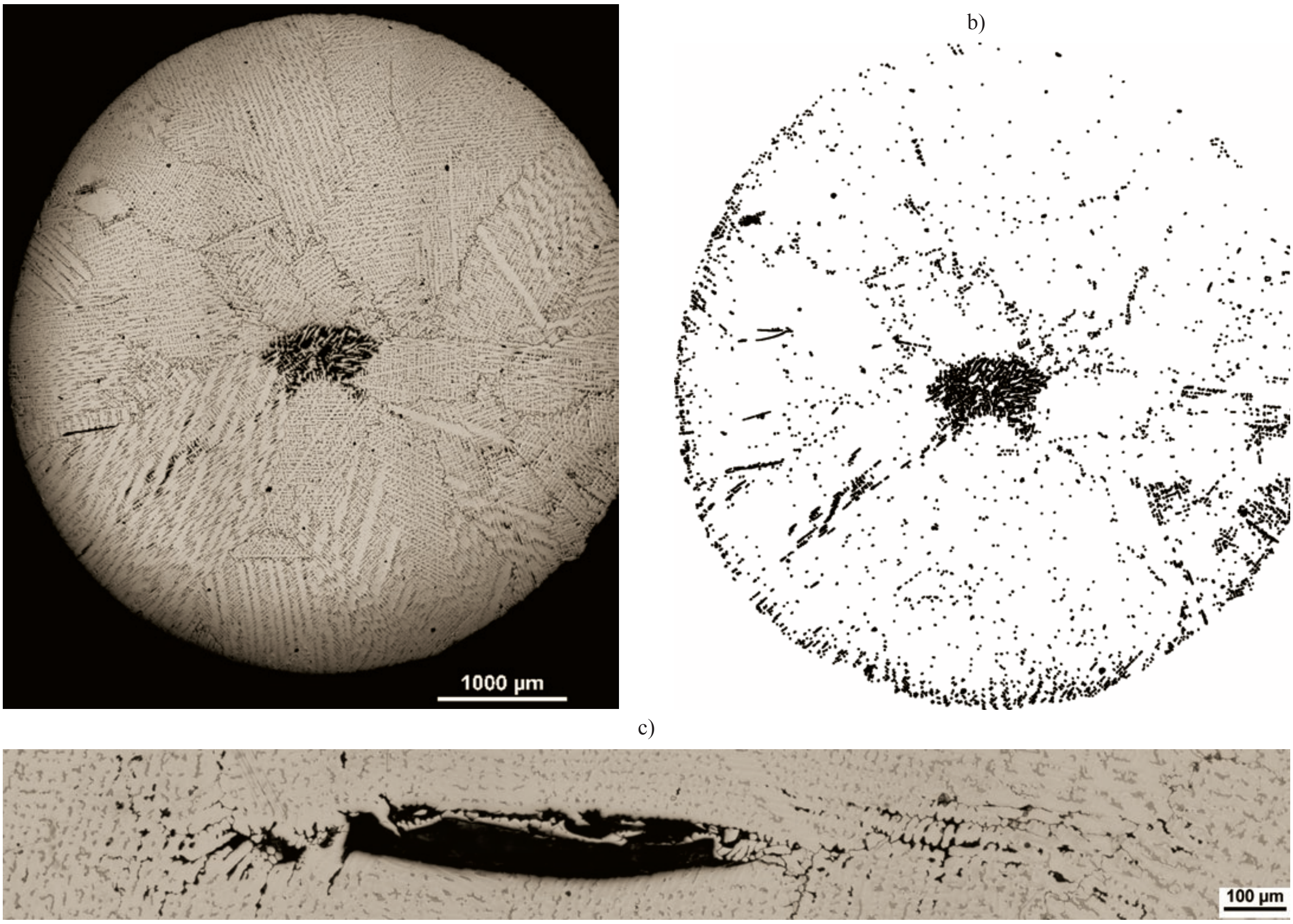

Fig. 7. a) A microstructure of selected element from Fig. 6, b) objects mask (shrinkages), c) longitudinal failures in a longitudinal section of a selected element

***Acknowledgments*:**
This article was created as a part of a research project of the National Science Centre no. 2011/01/N/ST8/07774.

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Karolina BEER, M.Sc. (Eng.)
Krzysztof PAŁKA, Ph.D. (Eng.)
Prof. Barbara SUROWSKA, Ph.D., D.Sc. (Eng.)
Mariusz WALCZAK, Ph.D. (Eng.)

Department of Materials Engineering
Faculty of Mechanical Engineering; Lublin University of Technology
ul. Nadbystrzycka 36; 20-618 Lublin
e-mails: k.beer@pollub.pl, k.palka@pollub.pl, b.surowska@pollub.pl, m.walczak@pollub.pl