

# Influence of Internal Scrap on Mechanical Properties of Selected Cobalt Alloys

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Received: 2 June 2017/Accepted: 18 September 2017/Published online: 9 November 2017

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## Abstract

This paper presents the results of mechanical tests carried out on two different commercially available cobalt alloys applied in dental prosthetics for the production of frame dentures. The test samples were obtained by the method of investment casting using as a charge pure primary materials and pure primary materials mixed with various additions of process scrap (25, 50, and 75%). The tests showed that the alloys could not reach the mechanical properties reported by the manufacturer in either case. In the case of the alloy without the addition of tantalum, the general conclusion was that both the plastic and strength properties decreased with increasing amounts of the introduced process scrap. The mechanical properties (mainly elongation) of the alloy containing Ta reached the highest values in the samples containing 75% of the process scrap. Examinations of fractures carried out by SEM have revealed their varied character – ductile or transcrySTALLINE. All of the samples tested showed the presence of dendrites and solidification areas, with shrinkage porosity occurring in the internal sample zones.

## Keywords:

cobalt alloy, mechanical properties, fracture, scrap

## 1. INTRODUCTION

Along with titanium alloys, nickel alloys and Cr-Ni steels, cobalt alloys belong to the group of common metal alloys that are widely used in medicine. Almost a century ago, the United States introduced the first cobalt alloy with chromium and molybdenum to dental surgery. The minimum chromium and molybdenum content in the alloy was 25% and 4%, respectively [1]. Contemporary cobalt alloys for biomedical applications are modifications of that alloy. In the as-cast state, the structure of cobalt alloys is comprised of the solid solution of chromium, molybdenum, and carbon in cobalt (and additionally, carbide precipitates) [2]. Occasionally, the CoCr phase may also appear in the alloy structure [3].

Cobalt alloys are characterized by satisfactory mechanical properties (e.g., elastic modulus); due to this fact, it is possible to manufacture products with thin walls and, as a consequence, lower weight [4]. The beneficial combination of high mechanical properties and relatively low manufacturing costs has opened a wide range of applications for cobalt alloys in dentistry, mainly for frame dentures, braces, and prostheses on latches, bolts, and locks [3].

Due to the intricate shape of these castings (including the numerous design modifications introduced to satisfy the individual biological needs of each patient and, additionally, the tendency of cobalt alloys to undergo the strengthening process during production), the implementation of

serial production is not possible. Products cast from these alloys are made by the investment technique. The use of investment casting in the manufacture of prosthetic parts generates large volumes of process scrap, including gating systems, casting cones, and rejects. Manufacturers allow the possibility to use scrap as part of the charge, but it should be remembered that any scrap metal introduced to the charge can influence the strength properties of the cast parts (among others) [5–11]. Therefore, an attempt was made in this study to determine the mechanical properties of samples cast from cobalt alloys containing the addition of process scrap.

## 2. TEST MATERIAL AND METHODOLOGY

Two cobalt alloys used in dentistry for the manufacture of frame dentures were chosen for the study. The chemical composition of these alloys is shown in Table 1.

**Table 1**  
Chemical composition of test alloys [12]

Alloy	Chemical composition, wt.%				
	Co	Cr	Mo	Ta	Si
A	64.6	29	4.5	–	–
B	62.0	30	5.5	1.2	1.2

From the selected alloys, cylindrical specimens with diameter  $\varphi = 5$  mm and length  $l = 80$  mm were cast in a dental prosthetics laboratory. The charge was composed of pure primary materials (samples labeled A1 and B1) and pure primary materials mixed with the addition of process scrap introduced in different amounts (samples labeled A2–A4 and B2–B4). The percent content of the introduced process scrap is shown in Table 2.

**Table 2**  
Percent content of process scrap added to test alloys

Sample designations		Content of process scrap added to test alloys, %
A1	B1	–
A2_25	B2_25	25
A3_50	B3_50	50
A4_75	B4_75	75

From the investment cast rod-shaped test pieces, specimens were prepared for the examination of non-metallic inclusions and the performance of a static tensile test.

Specimens for the evaluation of non-metallic inclusions were after cutting, grinding, and polishing examined under a Neophot 32 light microscope at 400 $\times$  magnification.

The mechanical properties of the selected cobalt alloys were determined in a static tensile test performed on an Instron 5566 testing machine. The specimens were stretched at room temperature at a constant strain rate of  $10^{-4}$  1/s.

The fractures formed during specimen failure were examined under a JSM 7100F scanning electron microscope. The observations were conducted at magnifications ranging from 100 to 500 $\times$ .

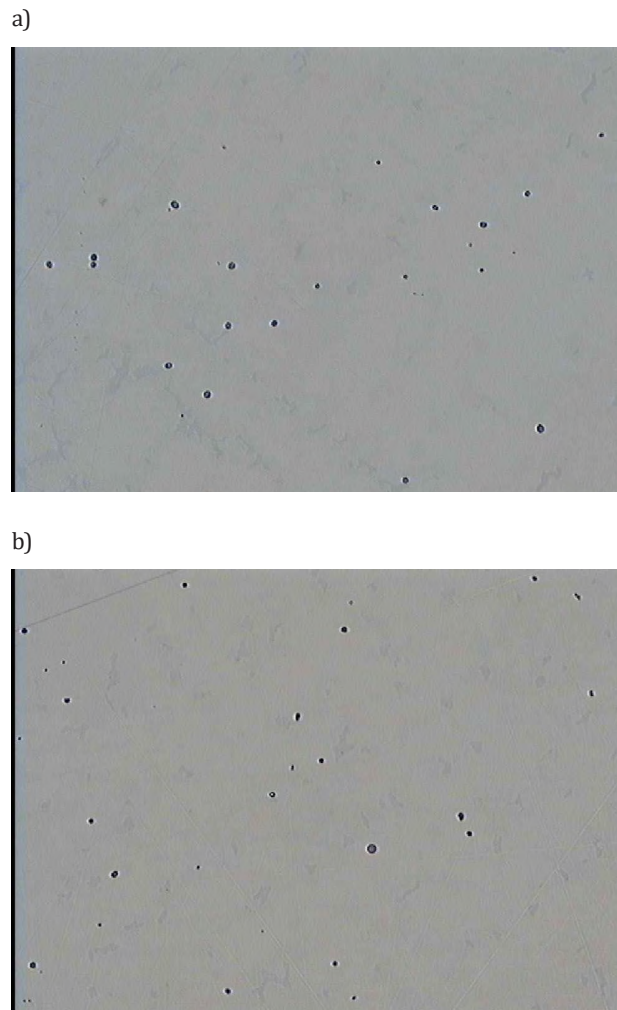
### 3. RESULTS AND DISCUSSION

Figure 1 shows the non-metallic inclusions present in the examined alloys. The observed precipitates are characterized by different shapes (globular and irregular), different sizes, and an uneven distribution on the examined surfaces.

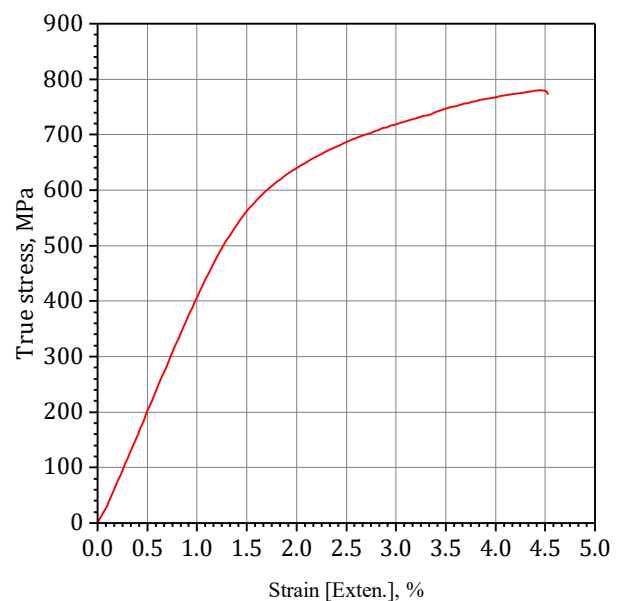
Studies carried out by light microscopy did not reveal any major influence of the process scrap content on changes in the morphology of the inclusions present in the test samples.

The results of the static tensile test have shown that failure of the specimens occurred at different points in the measurement area, irrespective of the amount of process scrap added to the examined material.

From the stress-strain curves plotted during tensile testing (see sample diagram in Figure 2), it follows that the tested materials have no yield point.



**Fig. 1.** Examples of non-metallic inclusions present in selected samples: sample A2\_25 (a); sample B2\_25 (b) light microscopy, magnification 400 $\times$



**Fig. 2.** Example of stress-strain curve plotted for investigated alloy

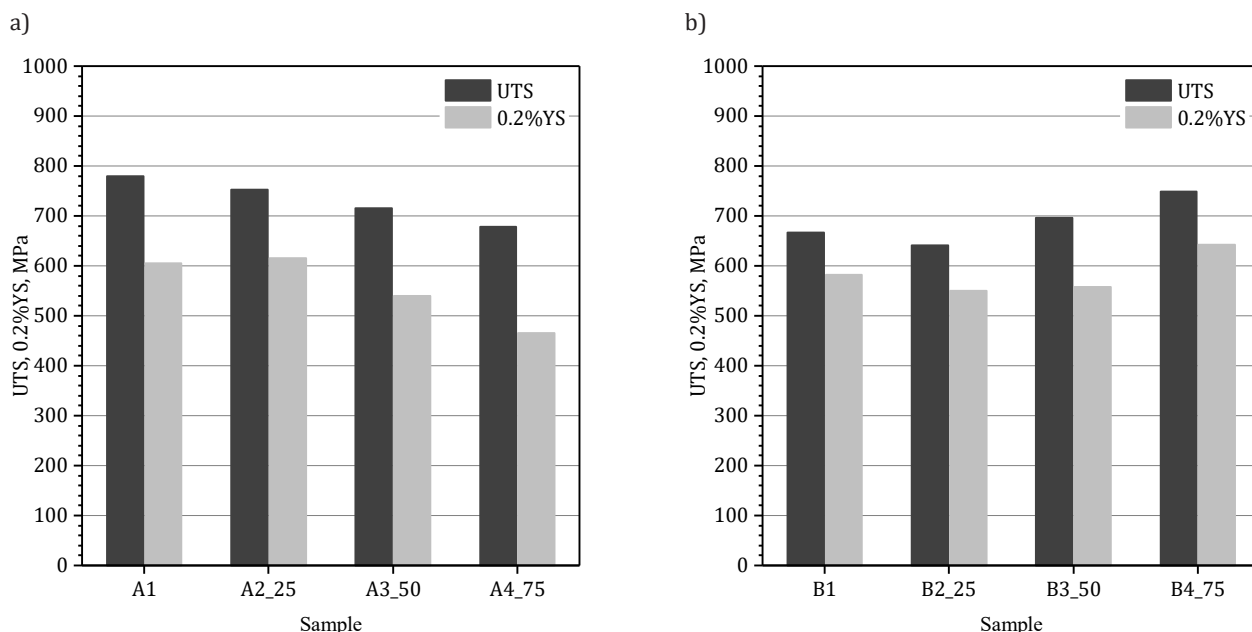


Fig. 3. Tensile strength UTS and yield strength 0.2%YS changing in tested alloys with changing scrap metal addition – Alloy A (a) and Alloy B (b)

Mechanical properties of the samples subjected to static tensile test are shown in Figures 3 and 4 and summarized in Table 3.

Table 3  
Mechanical properties of the tested cobalt alloys

Sample	UTS, MPa	0.2%YS, MPa	EL, %
A1	779	605	2.58
A2_25	752	615	2.16
A3_50	716	540	1.66
A4_75	678	466	2.00
B1	667	582	0.75
B2_25	641	550	1.50
B3_50	696	558	2.57
B4_75	749	642	3.75

The obtained mechanical properties of the alloys tested differ greatly from the values given in the literature [12].

Based on the obtained data (Fig. 3a), it was found that the mechanical properties of the tested materials decreased with an increasing scrap metal content in the alloy (the only exception is the yield strength obtained in the sample designated as A2\_25).

With the introduction of 25% of process scrap, the tensile strength of the material designated as B was lower than the strength of the starting alloy (Fig. 3b). Samples containing 50% and 75% of process scrap in their composition were characterized by tensile strengths higher than the strength of the starting material.

The yield strength of the samples containing 25% and 50% of process scrap was lower than the yield strength of the starting material. The highest yield strength was achieved by the material designated as A4\_75 containing 75% process scrap. Except for the alloy sample containing 75% process scrap, the elongation of the material designated as A decreased with an increasing content of the added scrap (Fig. 4). In contrast, the elongation of the material designated as B increased with an increasing content of process scrap. To explain the surprising impact of the increase in the amount of scrap introduced into the alloys (primarily Alloy B) on the improvement of tensile strength and elongation, further tests should be carried out.

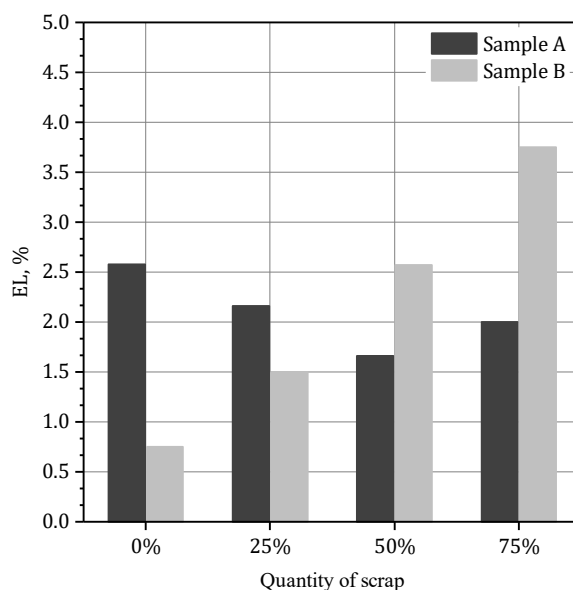
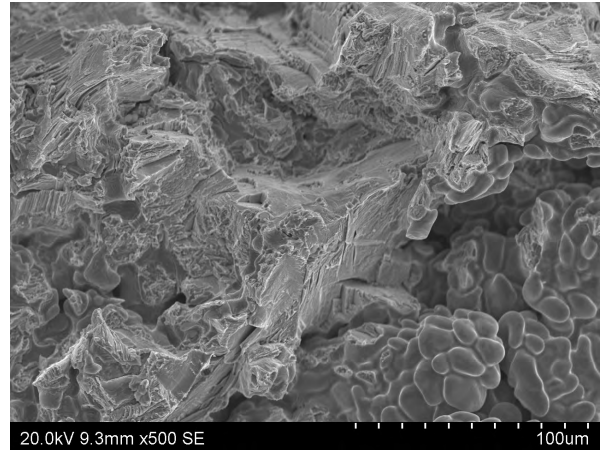
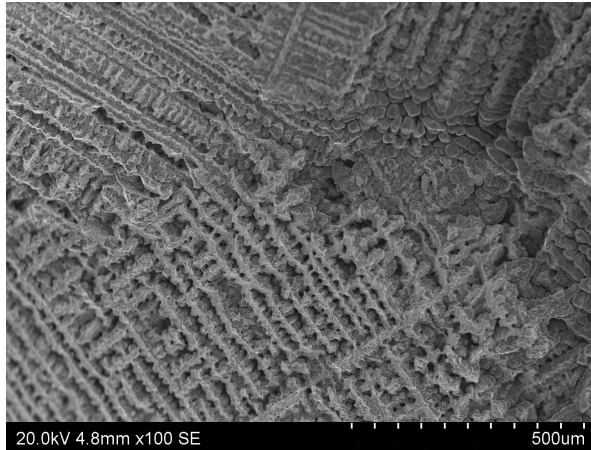


Fig. 4. Elongation changing in tested alloys with changing scrap metal addition

a)



b)

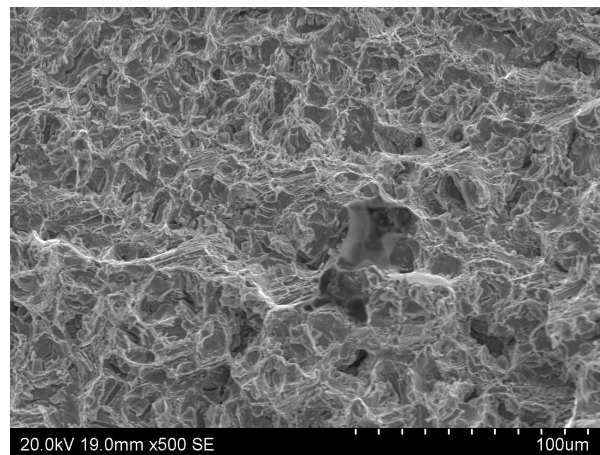
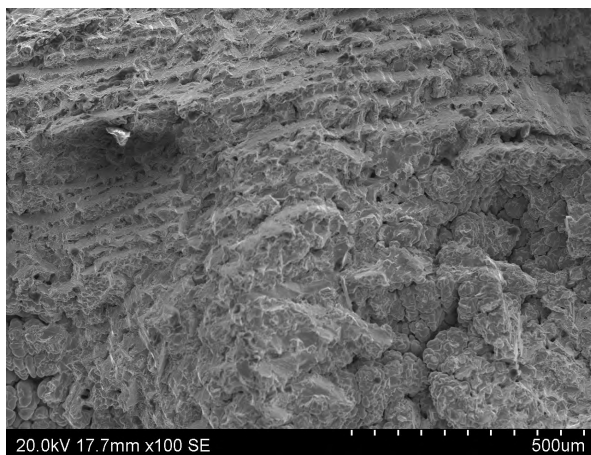


Fig. 5. Sample images of fractures formed in alloys during static tensile test – Alloy A (a) and Alloy B (b)

Figure 5 compares the SEM images of the fractures. Detailed examinations of the fractures formed during the static tensile test have revealed a dendritic pattern visible at low magnifications as well as shrinkage porosity occurring in the sample interior.

The observed fractures have different natures (ductile or transcrystalline). In some areas, sharp edges, large corrugations, and recesses occur.

#### 4. CONCLUSIONS

The results of the studies lead us to the following conclusions:

1. In all of the tested materials, there are non-metallic inclusions characterized by different shapes and distributions.
2. From the results of a static tensile test, it follows that the tested material has no yield point.
3. The mechanical properties of the samples subjected to the static tensile test are definitely inferior to the values given by the manufacturer.
4. The values of UTS, 0.2%YS, and EL decreased in the tested Alloy A with an increasing content of process scrap.

5. Adding process scrap to the alloy designated as B makes the strength properties of this alloy decrease at first, followed by an increase. The elongation of the alloy designated as B increases with an increasing addition of process scrap. The maximum mechanical properties were obtained in the alloy designated as B4\_75.

6. Factographic studies have revealed the presence of shrinkage porosity in the central part of the samples.

7. The examined fractures are of a ductile or transcrystalline nature.

#### Acknowledgements

The study was done as part of the bachelor's thesis of Dęsoł B. (2017). *Badania właściwości mechanicznych stopów kobaltu*. AGH University of Science and Technology.

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