Comparison of the mechanical properties of a CoCr sinter alloy with a CoCr casting alloy

As good as cast

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Amann Girrbach is putting Ceramill Sintron, a dry millable CoCr material for processing using CNC technology, on the market. This is possible because the material – similar to a partially sintered zirconia blank in dentistry – is in a preliminary state which can be easily processed. After the required frameworks have been milled from the blank they are debinded and densely sintered in a downstream process.The following article is intended to clarify whether the final mechanical properties of Ceramill Sintron are comparable with those of established CoCrMo casting alloys.

Introduction

In times in which all-ceramic restorations are proverbially on everyone's lips, it appears that materials which have been used successfully over many years still retain their high importance as dental restoration materials. Special non-precious metal alloys (NPM) are among the preferred material groups for fabrication of a restoration with a long-term prognosis. This class of alloy has become established in the dental market over decades as a cost-cutting alternative to precious metal alloys due to their good mechanical properties, biocompatibility and porcelain veneering properties etc. Special CoCr alloys are widely used for the fabrication of restorations, particularly if high demands are placed on the strength of the framework.

Processing of non-precious metal alloys up until now has mainly only been possible using the manual casting technique. CoCr frameworks were previously fabricated in the CAD/CAM technique via selective laser melting (SLM) or milling from blanks, which already had the final properties of the material.
The two latter processing options, however, were associated with enormous acquisition costs for the respective production equipment and were therefore mainly reserved for production centres that specialised in industrial fabrication of CoCr restorations.

The easy processing properties of a new CoCr sinter metal blank, which is in a preliminary material state technically as a green body, means that CoCr restorations can now also be fabricated using CAD/CAM in dental laboratories, which do not have industrial standard production machines [1]. The consistency of the blank, which is manufactured in a powder metallurgical process, enables it to be dry milled without additional cooling on milling machines. This easy processing is based on the fact that the blank consists of a powder atomised CoCrMo alloy, whereby the cohesion of the powder particles is guaranteed by an organic binder.

After the milling process (CNC controlled), the framework produced is debinded in a special sinter furnace and densely sintered under a shielding gas atmosphere. The material achieves its mechanical properties on completion of the sinter process, which is accompanied by a volumetric shrinkage of approximately 10 %. The study described below is intended to answer the question of whether the final mechanical properties of the CoCr sinter metal are comparable to those of established CoCrMo casting alloys that have been used successfully over many years in the dental market.

Description

The aim of this materiological study was to compare the mechanical properties of

Fig. 1
Fixed restoration fabricated using Ceramill Sintron CoCr sinter material

Literature

QR CODE:

The literature list can be obtained using the QR code above or at www.teamwork-media.de. Follow the link "Literatur-verzeichnis" in the eft sidebar.

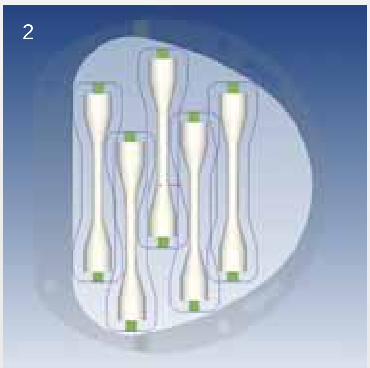


Fig. 2 Using this dataset test pieces were milled from wax and Ceramill Sintron for the tensile test

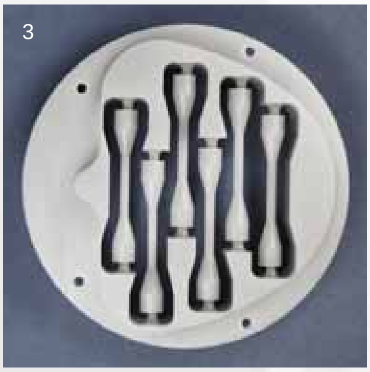


Fig. 3 Tensile test pieces in the wax blank. After separation, the test pieces were sprued, invested and cast using Girobond NB

Fig. 4 The test pieces for the tensile tests, which were milled from the sinter metal Ceramill Sintron in the green body state

conventionally fabricated dental precision castings (Girobond NB) with the properties of a milled and densely sintered sinter metal alloy (Ceramill Sintron). Both non-precious alloys are manufactured and sold by Amann Girrbach. A comparison of the two manufacturing processes of the test pieces required and the analysis of the results are also presented in this article. Both alloys are used for fabricating fully anatomical and anatomically reduced crown and bridge restorations (Fig. 1). As a variety of non-precious metal casting alloys have been used for many years in crown and bridge work, it must be established whether the mechanical properties of a sinter alloy meet the strength requirements for fabricating fixed or removable restorations in accordance with DIN EN ISO 22674 [2].

Fig. 5 The sinter metal is debinded and densely sintered in the special Ceramill Argotherm furnace

Material and method

In order to record all relevant mechanical properties of the two alloys, standardised test pieces were fabricated for performing a tensile test according to DIN EN ISO 22674.

More specifically, six tensile test pieces were fabricated and tested for each alloy and processing technique. CAD/CAM-supported fabrication of the test pieces was based on the respective datasets for milling production (Fig. 2).

The prototypes of the tensile test pieces for the casting alloy Girobond NB were milled from wax blanks (Ceramill Wax, Amann Girrbach) based on the same CAD/CAM dataset (Fig. 3). The Ceramill Sintron test pieces were milled from a corresponding sinter metal blank taking the expansion factor into consideration (Fig. 4). As dental restorations could be fabricated in the same way from both materials, this method of fabricating the test pieces simultaneously takes into account any existing influence of milling on the quality of the test piece. All test pieces were separated from the CAD/CAM blanks after milling and the end faces were trimmed level.

The Ceramill Sintron tensile test pieces were then densely sintered under shielding gas atmosphere (argon) in the Ceramill Argotherm (Fig. 5), which was specially designed for Ceramill Sintron. The test pieces were supported by a layer of beads in the Argovent sintering tray during the sintering process (Fig. 6) and removed in the densely sintered state at the end of the programme.

After separation from the blank, the milling wax test pieces were sprued using appropriate wax wire, placed in a casting ring (Fig. 7) and invested according to the manufacturer's instructions using Giroinvest Super universal investment (Amann Girrbach).

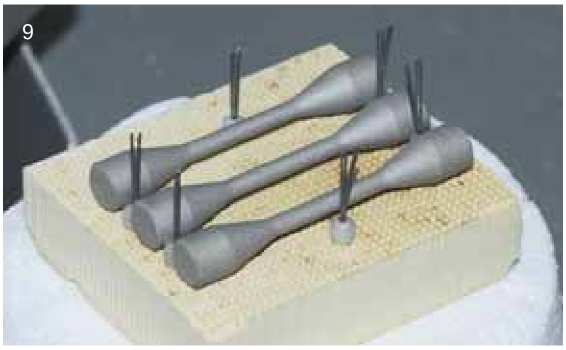
The Girobond NB alloy was also cast according to the manufacturer's instructions using the Heracast IQ (Heraeus Kulzer) vacuum pressure casting machine. After casting, the test pieces were devested, the sprues were cut off (Fig. 8) and then the sprue contact areas were trimmed.

According to DIN EN ISO 22674 bonding alloys must not only be tested with regard to their initial strength values but additional test pieces must also be subjected to heat treatment before testing. The heat treatment corresponds to the sequence of porcelain firing cycles prescribed by the manufacturer for processing the respective veneering porcelain. In the present study the firing cycle values for Creation CC veneering porcelain were used (Creation Willi Geller). The heat treat-

Fig. 6 The Ceramill Sintron tensile test pieces are supported on a layer of sinter beads for sintering

Fig. 7 The milled wax test pieces are sprued and placed in a casting ring for investing

Fig. 8 After cooling, the castings are devested and the sprues are separated from the test pieces



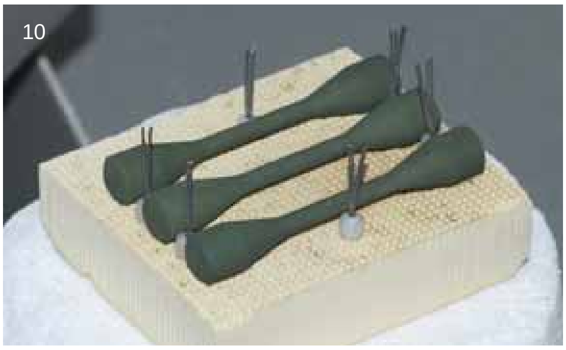


Fig. 9 and 10 Ceramill Sintron tensile test pieces before and after heat treatment

ment required in the strength test is intended to record changes in properties that could be caused by the porcelain firing cycles.

After casting or sintering, the test pieces which were not subjected to heat treatment, were sandblasted using aluminium oxide, grit size 110 µm and cleaned using a steam cleaner. The heat-treated test pieces were subjected to three porcelain firing sequences each with six firing cycles (Fig. 9 and 10). The temperature control of each firing cycle is shown in Table 1. The heat-treated test pieces were also sandblasted and cleaned. The six test pieces of cast and sinter alloy were each identically heat treated.

The DIN EN ISO 22674 standard only requires one firing sequence with an oxide firing and four porcelain firing cycles. In the test described in this article the parameters were intensified due to tripling of the porcelain firing cycles. This procedure was intended to take account of the complete remake of a porcelain veneer, which is sometimes necessary in clinical practice.

Strength test

The tensile test was performed in accordance with DIN EN ISO 22674. To perform the test the tension rods were clamped in the holder of a universal testing machine (Zwick) and pulled apart at a feed rate of 1.5 mm/min. until fracture (Fig. 11).

Hardness test

The hardness was also recorded in the study. Hardness is an important value for

Tab. 1 Firing chart of porcelain firing cycles with which some of the test pieces were heat treated

Firing	Start temperature	Close time	Temperature rate	Vakuum	Final temperature	Hold time
Oxide firing	550 °C	–	80 °C/min.	–	1000 °C	1 min.
1st Opaque	550 °C	6 min.	80 °C/min.	+	1000 °C	1 min.
2nd Opaque	550 °C	6 min.	80 °C/min.	+	950 °C	1 min.
1st Dentine	580 °C	6 min.	55 °C/min.	+	920 °C	1 min.
2nd Dentine	580 °C	4 min.	55 °C/min.	+	910 °C	1 min.
Glaze firing	600 °C	2 min.	55 °C/min.	–	930 °C	–

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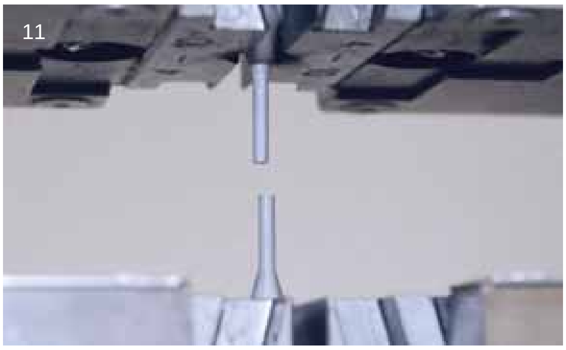

Fig. 11 One of the test pieces after the tensile test. The test piece was pulled apart at a feed rate of 1.5 mm/min. until fracture

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Fig. 12 Hardness test according to Vickers on embedded test piece head (hardness testing machine, Frank)

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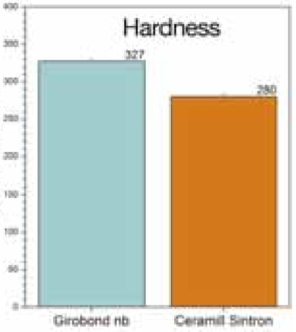

Fig. 13 Comparison of the Vickers hardness HV 10 of Girobond NB and Ceramill Sintron. The Vickers hardnesses of CoCrMo alloys in the literature are between 260 and 380 HV10

the trimming and polishing properties of the material (in the final state). Determination of the Vickers hardness was performed according to DIN EN ISO 6507-1 [3] on both the casting and sinter alloy and compared with one another. The test was performed on metallurgically prepared tension rod heads in each case (Fig. 12).

Results

The results are based on two test series performed in different locations. On the one hand on those of Amann Girrbach, which were ascertained within the framework of the batch test, and on the other hand on those of the strength tests with and without heat treatment. The latter were conducted at Tübingen University Hospital, Germany at the Section of Medical Materials and Technology at the Centre of Dentistry, Oral Medicine and Maxillofacial Surgery.

Hardness

The hardness of Ceramill Sintron is 280 HV10, which is approximately 50 HV10 below that of the Girobond NB casting alloy that was used as a comparison (Fig. 13).

This result is regarded as positive for the sinter material because if the hardness is too high, trimming and polishing is difficult for the dental technician. According to the literature the Vickers hardnesses of CoCrMo alloys are in a range of 260 to 380 HV10 [4]. The value for Ceramill Sintron is therefore at the lower limit of the CoCrMo class of alloys. An improved polishability, as can be attested for the material, has a positive effect on the surface quality of the dental restoration that can be achieved during preparation both in the dental laboratory and the dental practice. A high surface quality with a minimal depth of roughness counteracts increased abrasion on the opposing dentition. A high surface quality is therefore the best protection against non-physiological wear of the natural teeth, which occurs in direct contact with a dental restoration.

Strength

Stress-strain diagrams were created from all tensile strength measurements. The diagrams of Girobond NB (Fig. 14) and Ceramill Sintron (Fig. 15) both following simulated porcelain firing are presented in this article as examples.

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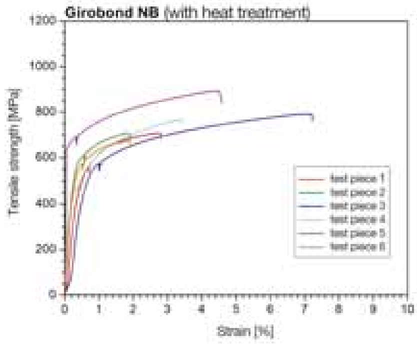

Fig. 14 Stress-strain diagrams of the six Girobond NB tension test pieces

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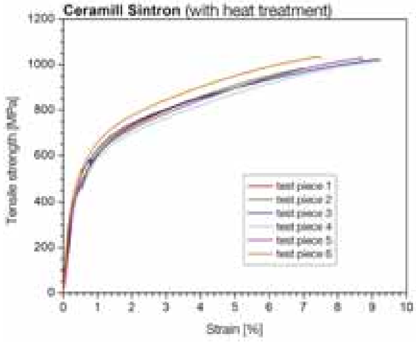

Fig. 15 Stress-strain diagrams of the six Ceramill Sintron NB tension test pieces

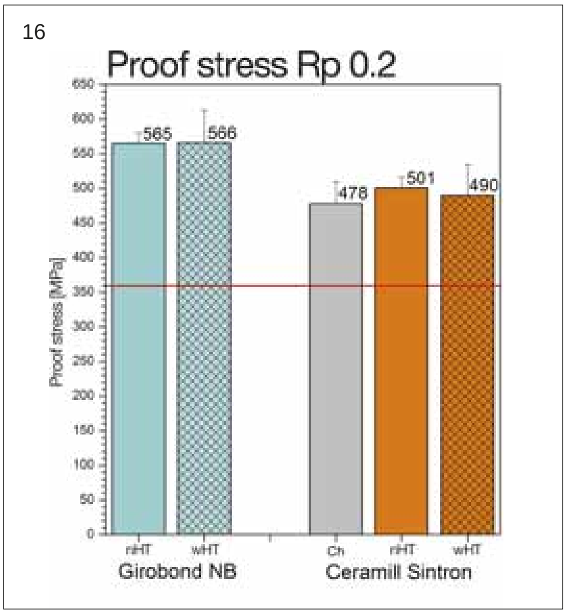

Fig. 16
Proof stress Rp 0.2. The red line represents the minimum requirement of the 0.2 % proof stress for Type 4 alloys

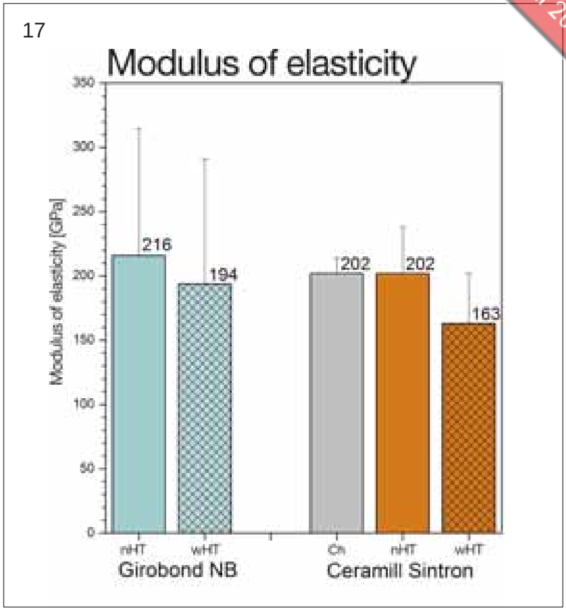

Fig. 17
The modulus of elasticity of different test pieces. nHT stands for “no heat treatment”, wHT for „with heat treatment“ and Ch denotes the value of the batch control from Amann Girrbach

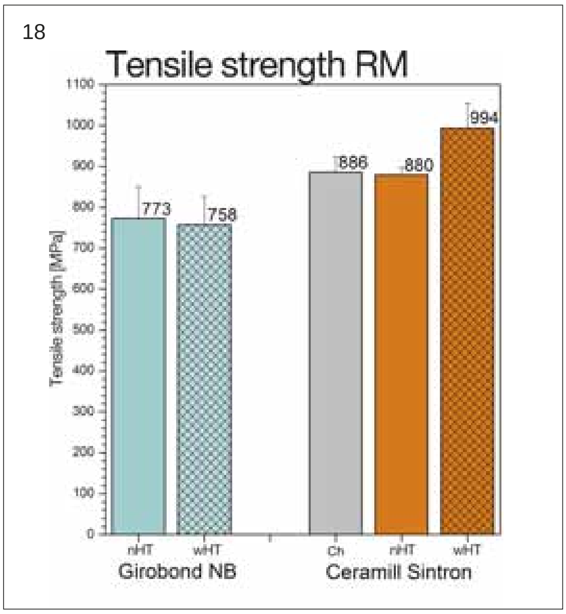

Fig. 18
The values recorded for the tensile strength. The mean tensile strength of Ceramill Sintron is approximately 100 MPa higher than that of Girobond NB

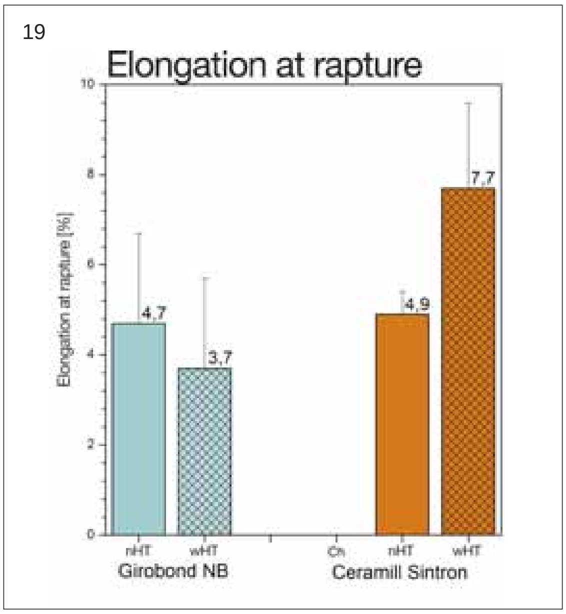

Fig. 19
The elongation at rupture of Ceramill Sintron is higher than that of Girobond NB casting alloy and increases significantly statistically due to the heat treatment

The parameters elongation at rupture A5, proof stress Rp 0.2, tensile strength Rm and the modulus of elasticity were evaluated in accordance with DIN EN ISO 22674.

The mechanical properties can be found in Figures 16 to 19. The results of Girobond NB casting alloy are always shown on the left and on the right are the results of Ceramill Sintron sinter alloy without and with heat treatment (nHT, wHT) and also the data of the batch test (Ch) from Amann Girrbach.

A very important parameter is the 0.2 % proof stress (Rp 0.2), which represents the transition from elastic to plastic deformation. According to DIN EN ISO 22674 Type 4 alloys must have a minimum value of 360 MPa. This is greatly exceeded by both alloys (cf. red line in Fig. 16). The mean values of Girobond NB are slightly higher than those of Ceramill Sintron. No influence of the heat treatment (simulated porcelain firing) on the proof stress was established with either material.

The modulus of elasticity denotes the material-specific resistance against deformation. This means that a material with a higher modulus of elasticity is stretched to a lesser extent when subjected to tensile stress [5], whereby more slender designs are possible, for example in the case of bridge connectors. Girobond NB and Ceramill Sintron exhibit comparable values in this respect (cf. Fig. 17). The mean value of Ceramill Sintron reduces slightly from 202 to 163 GPa as a result of heat treatment. In comparison a typical precious metal alloy is in the region of 110 MPa [6].

The mean tensile strength of Ceramill Sintron is approximately 100 MPa higher than that of Girobond NB and increases further as a result of heat treatment (cf. Fig. 18).

The elongation at rupture of Ceramill Sintron is higher than that of Girobond NB casting alloy and becomes significantly greater statistically due to the heat treat-

Fig. 20 Light microscopic image of an example of a Ceramill Sintron fracture surface (25x magnification) with homogeneous structure

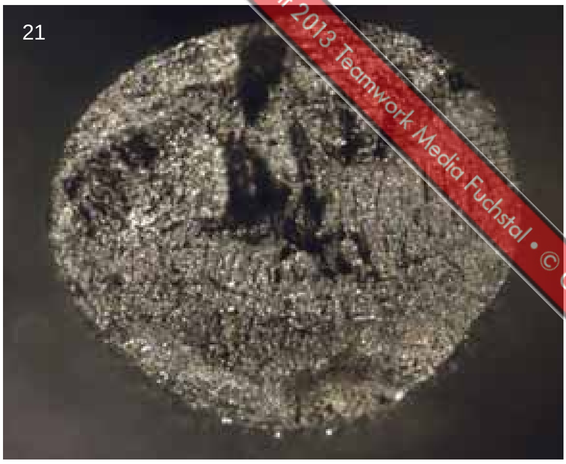

Fig. 21 Light microscopic image of an example of a Girobond NB fracture surface (25x magnification), the structure appears very irregular

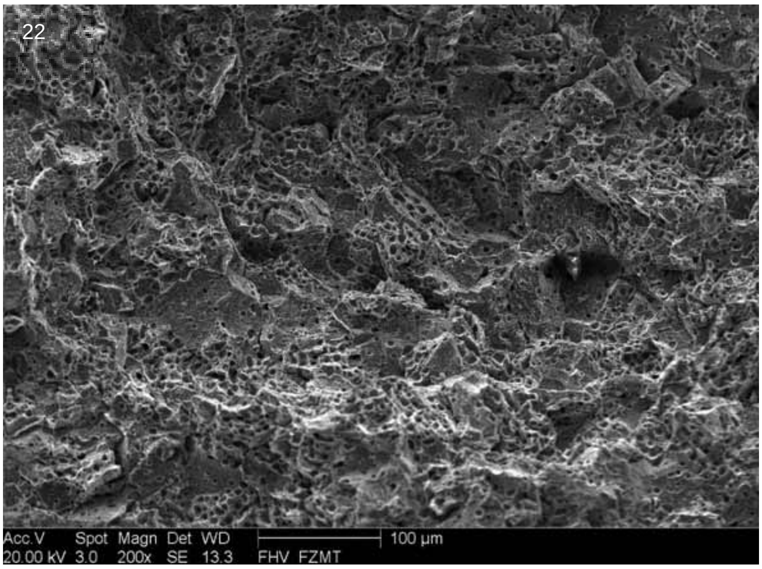

Fig. 22 Scanning electron microscopic image of a Ceramill Sintron fracture surface (without heat treatment, 200x magnification). This image highlights the homogeneity of the fracture surface

ment (cf. Fig. 19). This can be attributed to tension release of the sinter structure.

Microscopy

Images of the fracture surfaces were produced after the tensile tests. The fracture surfaces of Ceramill Sintron (Fig. 20) exhibited a more homogeneous structure in comparison with Girobond NB casting alloy (Fig. 21) (the Figures serve as an example for the fracture surfaces of the other test pieces).

The structure is further emphasised by the scanning electron microscopic image (Fig. 22).

Conclusion

The Ceramill Sintron test pieces which were subjected to heat treatment (similar to a standard firing programme) have the highest elongation at rupture and tensile strength. These are followed by Ceramill Sintron without heat treatment and Girobond NB with and without heat treatment.

In summary, it can be stated that in comparison with Girobond NB casting and bonding alloy Ceramill Sintron sinter alloy has comparable and, in the case of some parameters, even superior strength properties.

There are also similar evaluations in a comparison of laser-melted alloys with cast bonding CoCr alloys (for example [7, 8]). It can be concluded from the present results and the assessment of the SLM structures that production procedures such as laser melting and milling in the green body state with subsequent sintering can replace conventional casting procedures and that they also represent a logical step towards the digital workflow using alloys. ■

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The CV of the authors can be found at www.teamwork-media.de/download/authors/dd10_12_geis-gerstorfer.pdf or directly using the adjacent QR code.

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