A Quality Assessment of the Casting Process on Magnetic Keepers

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Purpose: The objective of this study was to qualitatively investigate the effect of the burn-out (mold) temperature, investment material, and casting alloy on the surface integrity of the Magfit EX keeper.

Materials and Methods: Forty-two Magfit EX keepers were waxed-up, invested in five investment materials (Beauty-Cast, Cristobalite, CM-10, Cera-Fina, Castorit-super), and subjected to burn-out temperatures ranging from 450 to 700°C at intervals of 50°C. The keeper samples were then cast into copings with three alloys (Castwell, Protor 3, Optimum) under standard conditions. The keeper surfaces were then examined under a microscope, and the compositions were assessed by an X-ray micro-analyzer in a scanning electron microscope (SEM). A new keeper served as control.

Results: At a burn-out temperature of 550°C, the keeper surface started to disintegrate. X-ray micro-analysis showed an increase in oxygen content with increasing temperature. At 700°C, the keeper surface disintegrated, and the composition differed markedly from that of the new keeper. The keeper surfaces were intact with all investments except those with Beauty-Cast. The keeper surfaces were found to be damaged when the casting alloy was Optimum.

Conclusions: Beauty-Cast investment with a burn-out temperature of 700°C is unsuitable for casting the Magfit EX keeper-coping unit. Also, high fusing alloys are not recommended for casting Magfit EX keepers.

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INDEX WORDS: magnet, burn-out temperature, casting alloy, investment

MAGNETS HAVE proven useful in aiding the retention of dental prostheses.[1] In general, a dental magnetic system comprises a magnet and a keeper. The keeper is made of a magnetizable alloy, providing a surface for attraction when approached by the magnet.[2] Additionally, in closed field dental magnets, the magnetic "circuit" is completed through the keeper. The Magfit EX magnetic retention system (Aichi Steel Corp., Nagoya, Japan) is a recently-developed, versatile system comprising of several magnetic attachments. The EX magnets are commonly used in retaining overdentures because of their strong retentive force, small size, and superior corrosion and wear resistance.[3] The Magfit EX keepers are supplied preformed by the manufacturer and are incorporated into nonmagnetic copings by the conventional lost wax casting technique before being cemented into the prepared abutment roots. The manufacturer recommends gold-platinum (Au-Pt) or a gold-silver-palladium (Au-Ag-Pd) casting alloy (Castwell, GC Corp., Tokyo, Japan) with a cristobalite investment material at a mold temperature of 700°C for fabricating the coping.

The Magfit EX preformed keeper is made of AUM20, a corrosion-resistant, high magnetic permeability stainless steel developed by the Aichi Steel Corporation. Its composition is shown in Table 1 (as control). Corrosion is a common problem in steels and is mainly due to oxidation.[4] It is well known that chromium (Cr) could suppress oxidation, and thus improve the corrosion resistance of steels.[4] The high Cr content (19%) in the keeper alloy would thus enhance the corrosion resistance of the keeper. In addition, the Cr content on the

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Table 1. Mean (SD) Surface Compositions of the Keepers at Different Burn-out Temperatures (wt%)

	Control (*n = 1*)	*450°C* (*n = 3*)	*500°C* (*n = 3*)	*550°C* (*n = 3*)	*600°C* (*n = 3*)	*650°C* (*n = 3*)	*700°C* (*n = 3*)
O	27.1	32.4 (5.0)	33.2 (5.5)	38.8 (4.5)	37.8 (6.2)	40.3 (7.6)	45.6 (11.0)
Cr	47.3	44.5 (6.6)	42.8 (3.1)	36.6 (6.5)	35.6 (8.4)	35.8 (9.8)	6.7 (4.4)
Fe	22.4	20.8 (2.5)	21.3 (2.0)	21.8 (3.3)	22.0 (2.8)	22.5 (4.2)	21.6 (3.9)
Al	2.0	1.0 (0.8)	0.9 (0.5)	0.5 (0.2)	–	–	–
Mo	1.2	1.3 (0.6)	1.8 (0.9)	2.3 (1.1)	1.9 (0.7)	1.4 (0.5)	1.3 (0.6)
Ag	–	–	–	–	1.9 (0.5)	–	0.7 (0.3)
Cu	–	–	–	–	0.8 (0.4)	–	20.1 (4.2)
Si	–	–	–	–	–	–	4.0 (1.3)
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

keeper surface has been increased to 65% up to a depth of 15 μm to prevent oxidation during the casting process.

Despite the presence of such a Cr-rich layer in the Magfit keeper, it was not uncommon to find keeper surfaces extensively discolored after casting the coping following the manufacturer's recommended burn-out temperature of 700°C. In some instances, the integrity of the Cr-rich surface layer appeared to have been breached, exposing the subsurface, which then might be expected to be susceptible to corrosion. In addition, at times, the keeper surface was found to be contaminated by the casting alloy. Removal of the latter could also result in possible damage to the Cr-rich surface layer.

Any distortion in the topography of the keeper surface would reduce peak retentive force significantly by increasing the effective distance between the former and the magnetic unit. It has previously been shown that the peak force is extremely sensitive to distance, and thus the need for close contact between the relevant surfaces.[2] To our knowledge, no data are available on the effects of casting variables on the surface integrity of Magfit EX keepers. This study thus proposes to qualitatively investigate the effect of burn-out temperature, investment material, and casting alloy on the surface integrity of Magfit EX magnetic keepers.

Materials and Methods

Forty-two Magfit 600 EX keepers were embedded in casting wax (Plastodent, Degussa, Germany). The wax was carved to a thickness of about 1 mm all-round, and a wax sprue former (3 mm in diameter) was attached to a corner opposite the holder (Fig 1). The pattern was secured onto a crucible former so that it was about 7 mm from the top of the casting ring. The casting ring was lined with one layer of wet Ring Liner (Whip Mix, Louisville, KY). The wax surface was wetted with Aurofilm (Bego, Bremen, Germany) to reduce its surface tension. It was then gently blown dry with air before investing.

Effect of Burn-Out Temperature

A gypsum-bonded investment, Beauty-Cast (Whip Mix), and Castwell, an Au-Ag-Pd alloy, were employed. The temperatures ranged from 450°C to the recommended 700°C at 50°C increments. The casting temperature was controlled at 1160°C as recommended by the alloy manufacturer. Compensation for casting shrinkage of the alloy was by the "thermal technique"

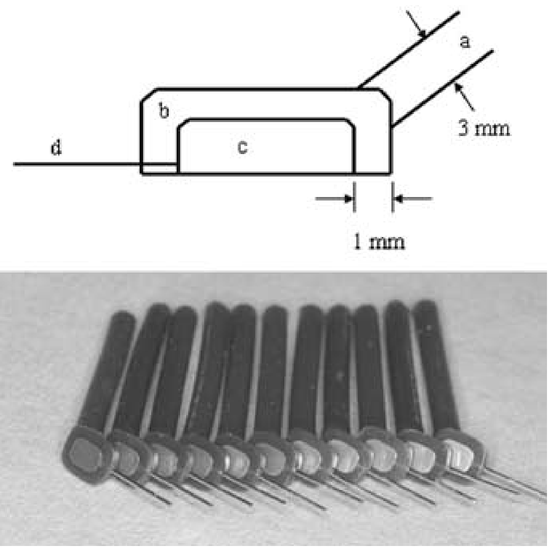

Figure 1. Sample preparation–(above) schematic diagram of a waxed-up and sprued keeper [(*a*) sprue former, (*b*) wax, (*c*) keeper, and (*d*) holder], (below) prepared samples.

as described below. Three samples were prepared for each temperature increment, and thus a total of eighteen samples were made.

Effect of Investment Material

Two phosphate-bonded investments, Cera-Fina (Whip Mix) and Castorit-super (Dentaurum, Pforzheim, Germany), and three gypsum-bonded investments, Beauty-Cast (Whip Mix), Cristobalite (Whip Mix), and CM-10 (Cendres & Metaux SA, Biel/Bienne, Switzerland), were tested. The final mold temperature was held at 700°C as recommended by the manufacturer. The casting alloy used was Castwell (GC Corp.) and the casting temperature was 1160°C as before. Three samples were prepared for each investment material, making a total of fifteen samples.

Effect of Casting Alloy

A nickel-chromium (Ni-Cr) alloy, Optimum (Matech Inc., Sylmar, CA); an Au-Pt alloy, Protor 3 (Cendres & Metaux); and Castwell (GC Corp.) were used. The investment used was Cera-Fina (Whip Mix), and the final mold temperature was held at 700°C. The casting temperatures followed the manufacturer's recommendations for each casting alloy. Three samples were prepared for each alloy, making a total of nine samples.

In all three studies, the investment materials were first hand mixed for about 15 seconds to wet the dry powder, and then mixing continued mechanically under reduced pressure for 60 seconds. The pattern was embedded and allowed to stand on the bench for 40 minutes for all investments except Cera-Fina, which was allowed a 90-minute bench setting as recommended by the manufacturer. From room temperature, the burn-out temperature was reached at a temperature rise rate of 8°C/min. The total burn-out time, including heat soaking, was carefully controlled to be 100 minutes. This included the time required to reach 700°C (85 minutes) and a holding time of 15 minutes. For lower burn-out temperatures, the holding time was adjusted as appropriate to give a total of 100 minutes. The casting (alloy) temperatures were controlled at 1160°C except Optimum, which was at 1485°C as recommended by the manufacturer of the alloy. Only pressurized steam was used to clean the surfaces of all castings. No sandblasting was used.

The keeper surfaces were examined visually under a microscope (StereoZoom 5, Bausch & Lomb, Rochester, NY) and analyzed using a scanning electron microscope (Cambridge S360, Leica, Cambridge, UK) provided with an X-ray micro-analyzer (Link eXL, Link Analytical, High Wycombe, Bucks, UK). The surface of a new keeper was examined and analyzed as a control.

Figure 2. Surface of a new keeper under the microscope.

The results of the X-ray analyses were quantified in mean weight percentage after ZAF (atomic number, absorption, fluorescence) correction.

Results

Effect of Burn-out Temperature

The surface of a new keeper (Fig 2) and its composition under the scanning electron microscope (SEM) and X-ray micro-analyzer are shown (Table 1). Chromium, iron, and oxygen were the main elements, with chromium in the majority. Small amounts of aluminum and molybdenum were also present. The surfaces of the cast keepers under the microscope at different burn-out temperatures are shown in Figure 3. At 550°C, some discoloration was observed on the edge of the keeper. The extent of the discolored area increased progressively with increase in temperature and was significant at 600 and 650°C. At 700°C, a complete disintegration of the surface was observed. The surface compositions from X-ray analyses are in Table 1. It was found that the oxygen content on the keeper surface increased with increasing burn-out temperature. In addition to the original elements, a small amount of silicon was also detected on the cast keeper surface. Traces of silver were also detected at 600 and 700°C. At 700°C, iron, oxygen, and copper became dominant, while a significant drop in chromium content was observed.

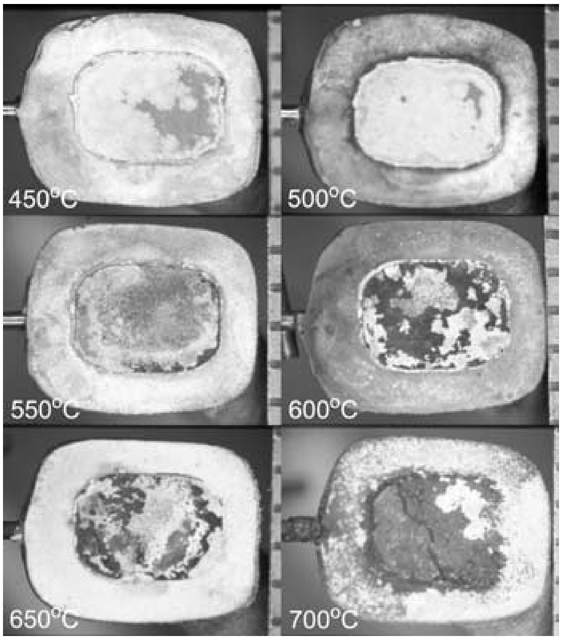

Figure 3. Surfaces of the keepers under microscope at various burn-out temperatures.

Effect of Investment Material

The surfaces and the compositions of the cast keepers using different investment materials are shown in Figure 4 and Table 2, respectively. Most of the keeper surfaces looked intact; however, the surface of the cast keeper was destroyed when the Beauty-Cast investment was used. X-ray micro-analysis showed an increase in the iron, oxygen, and copper content while a marked drop in chromium content was observed. The surface composition of a new keeper and those of cast keepers using Cristobalite and CM-10 were similar. An increase in the oxygen content was found with Cera-Fina and Castorit-super. An increase in iron content was also observed in Castorit-super samples.

Effect of Casting Alloy

The surfaces and compositions of the keepers using different casting alloys are shown in Figure 5 and Table 3. The keepers cast with Castwell looked intact, those cast with Protor 3 appeared darkened, while that with Optimum had disintegrated. The oxygen content was very high, higher than even the major element chromium in the Optimum samples. Small amounts of silicon, phosphorous, and molybdenum were also detected in all samples, but the silicon contents were found to be exceptionally high in the Optimum samples. Nickel and magnesium were also detected in the Optimum samples.

Discussion

The keeper is a crucial element in any magnetic retention system. It provides a magnetizable surface for the magnet to act on. Any change in its composition or surface topography after casting might affect the peak attractive force induced by the magnet.[2] To our knowledge, this is the first study reporting the effects of casting variables on the integrity of the surface of magnetic keepers. Although this is a qualitative study with limited sample size, it nevertheless provides new and relevant data in cast keeper-coping unit fabrication.

Effect of Burn-Out Temperature

The surface of a new Magfit EX keeper was intact and rich in chromium. At low temperatures such as 450 or 500°C, the keepers were basically

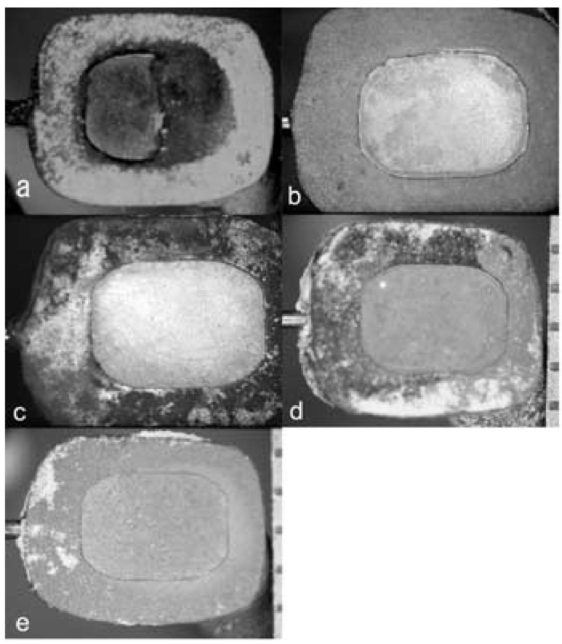

Figure 4. Surfaces of keepers under microscope with different investment materials at a mold temperature (burn-out) of 700°C. (*a*) Beauty-Cast, (*b*) Cristobalite, (*c*) CM-10, (*d*) Cera-Fina, (*e*) Castorit-super.

Table 2. Mean (SD) Surface Compositions of the Keepers with Different Investment Materials (wt%)

	Control (*n* = 1)	*Beauty-Cast* (*n* = 3)	*Cera-Fina* (*n* = 3)	Castorit-Super (*n* = 3)	*Cristobalite* (*n* = 3)	*CM-10* (*n* = 3)
O	27.1	47.8 (10.3)	48.2 (8.7)	47.3 (9.5)	36.3 (8.6)	32.8 (7.9)
Cr	47.3	7.4 (3.8)	32.7(8.9)	21.4 (8.4)	40.0 (6.2)	42.8 (3.4)
Fe	22.4	23.5 (3.3)	15.0 (2.9)	23.2 (3.4)	21.7 (4.4)	22.5 (3.8)
Al	2.0	–	1.0 (0.4)	1.3 (0.4)	0.5 (0.2)	1.1 (0.3)
Mo	1.2	0.5 (0.1)	0.9 (0.3)	1.5 (0.5)	1.5 (0.4)	0.8 (0.2)
Ag	–	0.5 (0.3)	–	–	–	–
Cu	–	18.2 (7.5)	–	–	–	–
Si	–	2.1 (1.3)	0.7 (0.2)	4.9 (1.8)	–	–
P	–	–	1.5 (0.5)	0.4 (0.1)	–	–
Total	100.0	100.0	100.0	100.0	100.0	100.0

unaffected; however, at higher temperatures, the degree of oxidation of the keeper surface increased. Since magnetic force is highly sensitive to the distance between the keeper and the magnet, the oxides and other contaminants on the surface of the keeper could make it uneven and thus have a significant detrimental effect on the peak retentive force attained.[2] Although the surface could be smoothed and polished using ordinary laboratory techniques, it is unknown whether these procedures might remove the Cr-rich layer and thus affect the corrosion resistance of the keeper. At 700°C, the subsurface was exposed due to the detachment of a part of the surface layer. The copper and silver detected were probably from the casting alloy, while the silicon is likely to be from the investment mold. Therefore, the use of burn-out temperature at 700°C as recommended by the manufacturer of the magnetic system was not supported. It could also be concluded that the lower the burn-out temperature, the better the maintenance of the integrity of the keeper surface.

Effect of Investment Materials

In the three gypsum-bonded investments tested, the keeper surfaces were found to be destroyed only when Beauty-Cast was used. Moreover, additional materials such as copper and silicon were also found. The former probably was from the casting alloy, while the latter most likely was from the investment material. With the other two investment materials, CM-10 and Cristobalite, no destruction was found on cast keeper surfaces. The reason for keeper surface destruction only in Beauty-Cast samples is unknown, since all three gypsum-bonded investments investigated share the same main composition. The differences in minor components such as modifiers, reducing agents, and pigments might therefore be the

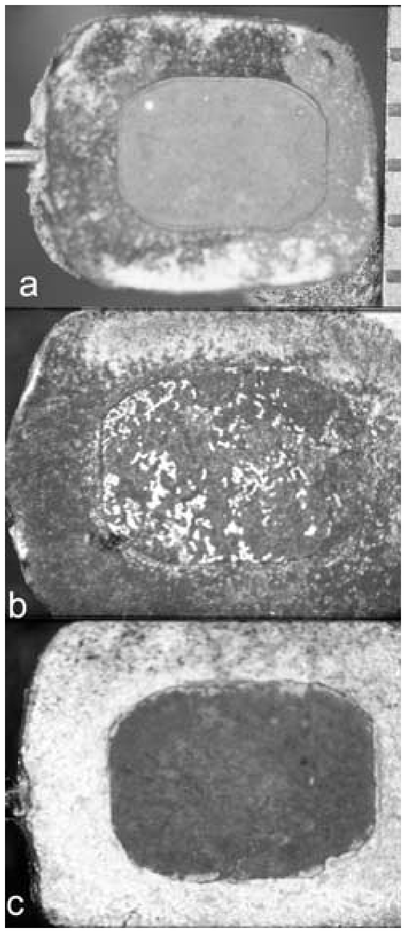

Figure 5. Surfaces of keepers under microscope, with different casting alloys. (*a*) Castwell, (*b*) Optimum, (*c*) Protor 3.

Table 3. Mean (SD) Surface Compositions of the Keepers with Different Casting Alloys (wt%)

	Control (n = 1)	*Castwell (n = 3)*	*Optimum (n = 3)*	*Protor 3 (n = 3)*
O	27.1	46.4 (8.8)	61.7 (11.2)	48.8 (7.9)
Cr	47.3	33.8 (7.3)	20.8 (9.1)	32.4 (6.5)
Fe	22.4	16.2 (5.5)	1.5 (0.6)	14.7 (4.6)
Al	2.0	0.4 (0.1)	–	1.1 (0.4)
Mo	1.2	0.9 (0.2)	0.6 (0.3)	0.7 (0.2)
Si	–	0.6 (0.2)	8.5 (3.7)	0.9 (0.3)
P	–	1.7 (0.7)	1.2 (0.6)	1.4 (0.8)
Mg	–	–	1.9 (0.9)	–
Ni	–	–	3.8 (1.2)	–
Total	100.0	100.0	100.0	100.0

cause, but this requires further investigation. The surfaces of the cast keepers looked intact with the two phosphate-bonded investment materials; however, the oxygen content on the keeper surface was slightly higher than that of a new keeper. It might be partly due to oxidation and partly due to some silica contaminating the keeper surface.

Effect of Casting Alloys

More oxidation occurred when Optimum was used. The silicon and magnesium detected on the cast keeper surface suggested that there could also be some degree of reaction between the metal oxides and the investment material.[5] Moreover, the nickel found indicated that the casting alloy probably had contaminated the keeper surface. The high casting temperature of 1475°C of Optimum could be the cause of such extensive oxidation and reactions. Hence, the use of alloys of high melting temperatures such as nickel-chromium and cobalt-chromium should be avoided when casting Magfit EX keepers. The samples obtained from Castwell and Protor 3 looked basically the same. Apart from a slightly higher oxygen content, they resembled the spectrum of the new keeper. No signs of the casting metal contamination were found. The trace amount of Si and P detected indicated that minor contamination may have occurred between the keeper and the investment material. Such contamination may affect the strength of the magnets on the keepers, but this requires further investigation.

Conclusions

A high burn-out temperature would produce undesirable oxidation on cast keeper surfaces. If Beauty-Cast is used, the burn-out temperature should be 500°C. The study also showed that both gypsum-bonded and phosphate-bonded investment materials were compatible with the Magfit EX keeper-coping system provided the above mentioned precautions were taken with Beauty-Cast. As for casting alloys, a low fusing precious alloy is preferred. Further investigation is needed to identify the incompatible constituents in the investments.

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