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Studies on the Castability of Pure Titanium（Part 3）Influence of casting pressure and sprue diameter on the titanium castability

TAKANORI YONEDA, AKIHIRO KUROIWA, YOSHIMASA IGARASHI, TAKAFUMI OHNO, YUUJI SEKIGUCHI, YOSHIHISA INOUE and SHINYA MIGO

Department of Removable Prosthodontics, Matsumoto Dental University School of Dentistry (Chief: Y. Igarashi)

Summary

We analyzed the external defects of castings with mesh grid patterns with 3 different kinds of phosphate bonded casting molds with 2 parameters（sprue diameter and casting pressure）. Castability with pure titanium was affected by the parameters of sprue diameter, and casting pressure with different casting molds. The sprue condition was the most affective casting condition in the all directional pressure type casting machine. In 2 types of casting molds, one was strongly affected by the casting pressure in castability and the other was scarcely affected by the casting pressure. The former type of casting mold had a low permeability.

Introduction

These are many studies[1,2] about castability of titanium.We have been analyzed the most optimal conditions in pure titanium castings to produce the complete castings without any defects nor shrinkage for years. We reported the tendencies in all directional pressure type casting machine that the high percentage of castability was gained[3] with high pressure of casting and low permeability of casting mold[4]. We wish to make it easy to cast for titanium in daily practice,they have applied the all dircctional pressure type casting machine to analyze the conditions of the sprue diameter and casting pressure on the castability evaluated in mesh grid pattern with three phosphate bonded investment of different permeability. The purpose of this study was to evaluated the external defects of castings with mesh grid patterns produced under 3 different kinds of phosphate bonded investments with the different sprue diameter and casting pressures.

Materials and Methods

1. Materials employed in this study

Materials employed in this study are shown in Table 1. JIS grade Ⅱ pure titanium（diameter：25 mm, height：9 mm, weight：20.026 + 0.033 g；Kobe Steel Ltd.）was used. Three kinds of metal sprues

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Table 1 : Materials and method

Casting machime	All-Directional pressure type AUTOCAST HC-Ⅲ	GC
Wax pattern	RN Ⅱ	DENTAURUM
Sprue	ϕ 0.88, 1.26, 2.11 mm Length 5 mm	Murakami
Mold material (Phosphate-bonded)	T-invest (L/P ratio = 0.13) T-invest C&B (L/P ratio = 0.14) MybestT-T (L/P ratio = 0.15)	GC GC SSS
Casting pressure	2, 4, 6, 8 kgf/cm^2	
Titanium	JIS Grade 2 (KS-50)	Kobe Steel Ltd.

with diameters of 0.88, 1.26 and 2.11 mm were used. Each sprue had a length of 5 mm. The distance to the pattern from the bottom of the casting mold was set at 10 mm. Three types of phosphate bonded casting molds with different permeabilities were employed in this study; including T-INVEST (Phosphate bonded, GC Co.), T-INVEST C&B (Phosphate bonded, GC Co.) and MYVEST-T (Phosphate bonded, SSS Co.). An all directional pressure type casting machine (AUTOCAST HC-Ⅲ : GC Co.) was regulated to casting pressures from 2, 4, 6 to, 8, kgf/cm^2, which were set according to at least one of the manufacturer's instructions.

2. Test samples

1) Wax patterns

Mesh grid type patterns were employed in pure titanium castability reported by Kuroiwa[5]. Mesh grid wax patterns (RN Ⅱ : DENTAURUM Co.) were cut in 7 by 7 grids which were attached to the ready casting wax (R 20 : GC Co.) as runner bars then sprued to the crucible formers (Fig. 1).

2) Preparation of cast ring, investing and casting.

Since the casting molds, T-INVEST and MYBVST-T, were originally developed for ringless castings, T-INVEST C&B was also used in a ringless condition applying the paper former as a temporary ring developed by Inoue[6]. This paper ring was specially conditioned by soaking bee's wax for 10 seconds to purge any water from the casting mold without changing the Liquid/Powder ratio. Height of every paper ring was set at 60mm. The L/P ratio and investing conditions in ring furnace of molds were executed according to the manufacturer's instructions (Fig. 2).

3) Assessing the castability and Statistical analysis

Cast were done 5 times for each condition. Castability was calculated by the previous method[3,5]. Results were statistically analyzed for mean, standard deviation and coefficient of variation. Simple regression curve and correlations between the parameters of castability and casting pressure were determined.

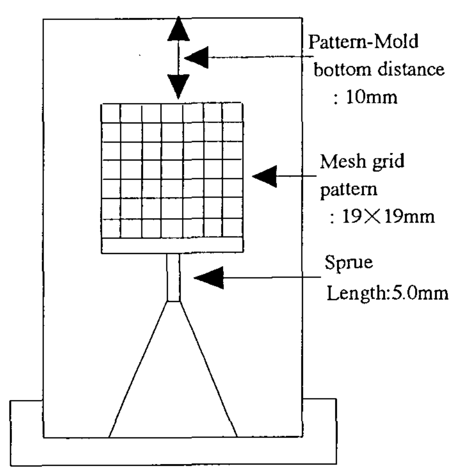

Fig. 1 : Schematic illustration of investing condition and mesh grid pattern

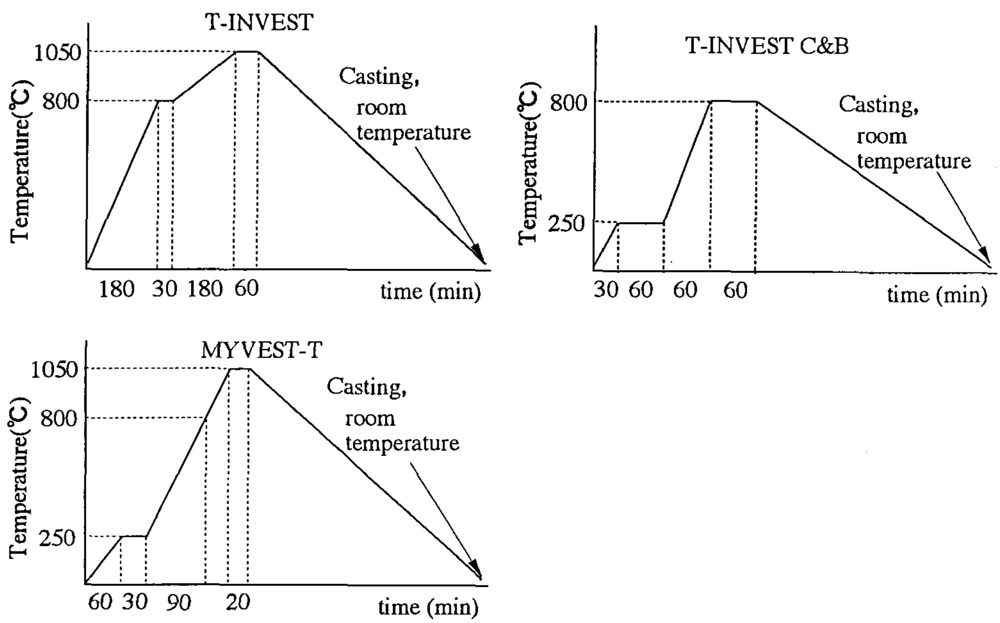

Fig. 2 : Heating mode of the casting molds

Results

Castabilities and their simple regression curves of T-INVEST are shown in Fig. 3. Mean, standard deviation, coefficient of variation and coefficient of correlation in castability are shown in Table 2. Castability with the sprue condition of 0.88mm was less than 20%. Under the sprue condition of 1.26 mm, it was gained 71.07% with a casting pressure of 2 kgf/cm^2, and 93.21% with a casting pressure of 8 kgf/cm^2. Castability showed 100% with the sprue of 2.11mm. There was no correlation between castability and the casting pressure. The castability and its regression curve of T-INVEST C&B are shown in Fig. 4. The mean, standard deviation, coefficient of variation and coefficient of correlation are shown in Table 3. Though a positive correlation between the castability and the casting pressure was demon-

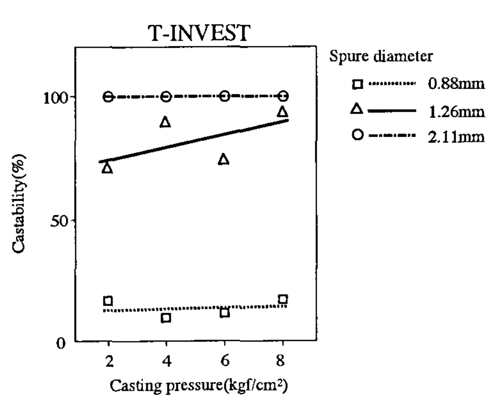

Fig. 3 : Effect of spure diameter and casting pressure on the castability

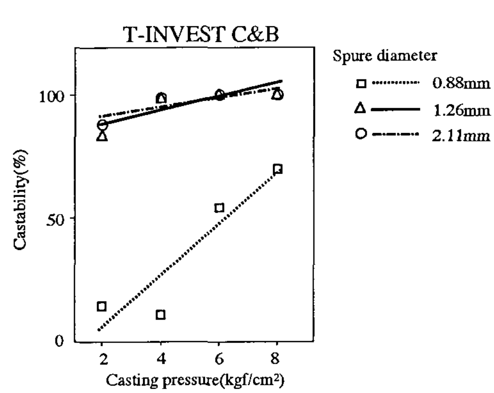

Fig. 4 : Effect of spure diameter and casting pressure on the castability

Table 2: Effect of sprue diameter and casting pressure on titanium castability in T-INVEST

		Casting pressure (kgf/cm^2)			
Sprue diameter		2	4	6	8
0.88 mm	Mean	16.43	9.64	11.43	17.14
	SD	14.85	10.83	18.11	13.87
	CV	90.38	112.34	158.44	80.92
	Correlation coefficient		0.14		
1.26 mm	Mean	71.07	89.29	73.93	93.21
	SD	24.07	7.25	16.00	14.19
	CV	33.87	8.12	21.64	15.22
	Correlation coefficient		0.60		
2.11 mm	Mean	100	100	100	100
	SD	0	0	0	0
	CV	0	0	0	0
	Correlation coefficient		–		

Mean, CV: (%) n = 5

Table 3: Effect of sprue diameter and casting pressure on titanium castability in T-INVEST C&B

		Casting pressure (kgf/cm^2)			
Sprue diameter		2	4	6	8
0.88 mm	Mean	14.29	10.71	54.29	69.64
	SD	22.29	18.56	22.89	27.52
	CV	155.98	173.30	42.16	39.52
	Correlation coefficient		0.92**		
1.26 mm	Mean	82.50	99.64	100	100
	SD	14.25	0.80	0	0
	CV	17.27	0.80	0	0
	Correlation coefficient		0.79		
2.11 mm	Mean	87.86	99.64	100	100
	SD	11.11	0.80	0	0
	CV	12.65	0.80	0	0
	Correlation coefficient		0.78		

Mean, CV: (%) n = 5 $^{**}P<0.05$

strated, castability was merely 69.64% with incomplete castings even with the highest pressure of 8 kgf/cm^2. Under 2 kgf/cm^2 pressure, castability showed more than 80% with 1.26mm and 2.11mm sprue conditions. It also showed 100% with complete castings at pressures greater than 6 kgf/cm^2. The castability and its regression curve of MYVEST-T are shown in Fig. 5. The mean, standard deviation, coefficient of variation and coefficient of correlation are shown in Table 4. A positive effectt was demonstrated of high casting pressure to the castability when the sprue diameter was 0.88 and 1.26mm. No com-

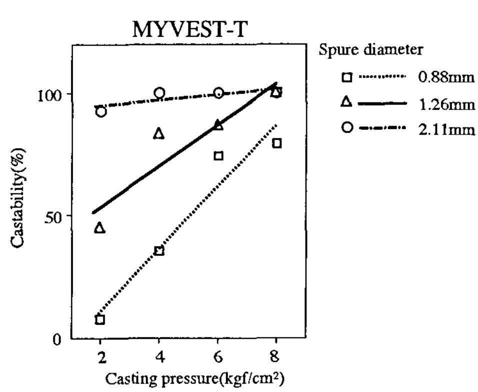

Fig. 5: Effect of spure diameter and casting pressure on the castability

Table 4 : Effect of sprue diameter and casting pressure on titanium castability in MYVEST-T

Sprue diameter		Casting pressure (kgf/cm²) 2	4	6	8
0.88 mm	Mean	7.86	35.36	73.93	79.29
	SD	17.57	33.82	21.34	35.12
	CV	223.54	94.34	28.87	44.29
	Correlation coefficient		0.97*		
1.26 mm	Mean	44.64	83.22	86.43	100
	SD	15.87	16.92	14.32	0
	CV	35.55	20.33	16.56	0
	Correlation coefficient		0.92**		
2.11 mm	Mean	92.50	100	100	100
	SD	8.96	0	0	0
	CV	9.69	0	0	0
	Correlation coefficient		0.77		

Mean, CV : (%) n = 5 *$P<0.01$, **$P<0.05$

plete castings were gained at the sprue of 0.88mm at any pressure conditions. Complete castings were accomplished at the sprue of 1.26mm with the highest pressure of 8 kgf/cm². With the sprue condition of 2.11mm, castability showed 92.50% at 2 kgf/cm² and 100% at 4 kgf/cm². A positive correlation was demonstrated between casting pressure and castability in sprue conditions of 0.88mm and 1.26mm analyzed by the simple regression curve.

Discussion

The goal of this study was to examine the use of titanium casting in daily practice. We applied the all directional pressure type casting machine to analyze the conditions of the sprue diameter and casting pressure on the castability evaluated in mesh grid patterns with 3 phosphate bonded casting molds of different permeabilities.

1. Influence of the sprue diameter

High percentage of castability was gained according to the enlargement of sprue diameter. The ratio between the volume of sprue and outer surface of sprue (Volume Surface Ratio ; V/S ratio), was 0.246 with a sprue of 0.88mm, 0.315 with a sprue of 1.26mm and 0.527 with a sprue of 2.11mm. Increases of sprue diameter corresponded with the volume of sprue compared to outer surfaces. Increases of the heat capacity of molten titanium caused the melting time to be prolonged, and a high percentage of castability was gained. This finding corresponded with the report of the vacuum and pressure type casting machine by Kuroiwa[5]. The diameter of sprue size should be a practically acceptable, since the laboratory work such as cutting and finishing are easily done with rather fine sprues. Therefore, the size of sprue should be as thin as possible to prevent defects. Since the castability of pure titanium was evaluated with mesh grid pattern objectives in this present study, the conditions of sprue diameter were not precisely defined. It is our duty to differentiate the conditions for complete castings in cases of clinical forms such as crowns and bridges and cast frameworks in dentures.

2. Casting pressure

Positive correlations between the castability and casting pressure were observed in T-INVEST C&B with a sprue of 0.88mm and MYVEST-T with a sprue of 1.26mm. This indicates the prompt intrusion of molten titanium to the mold caused by the increasing pressure and the amount of the molten metal per second increased to shorten the casting time. This tendency corresponded[4] with the conventional dental alloys. No positive correlations are observed in T-INVEST with a 0.88mm sprue at any casting pressure. Castability was less than 10% at any condition. Though slight positive increases were observed in castability with a sprue of 1.26mm, no positive correlations were observed between castability and casting pressure. Influence of the permeability of the casting mold especially the one at the surrounding wall of the mold acted as separating walls in the single casting chamber in this type of all directional pressure type casting machine. With the casting mold of high permeability, prompt[4,7] equalization of differential gas pressures of Argon occurred between the casting chamber and casting mold causing the casting force to fail. The permeability[8] with 3 different casting molds is shown in Fig. 6. The lowest one was in T-INVEST C&B, then MYBVST-T and T-INVEST was the highest. In case of T-INVEST with the sprue of 0.88mm, no changes were observed according to the various conditions of casting pressure. It was thought that even with a high casting pressure, differential pressure initiating the casting force would disappear before the internal pressure in the casting chamber reached to 2 kgf /cm², which is necessary for casting. High score of casting percentage was gained with the sprue of 2.11 mm in all 3 casting molds. This indicates positive influence of the sprue diameter. All results were comfirmed by 3 way analysis of variance: castability was considered dependent variable and sprue diameter, casting pressure and difference of casting molds as independent variables (Table 5). The value of ratio of contribution showed the greatest among three facters with regards to sprue diameter. These statisfical analysis indicate that the castability firstly affected by sprue diameter, then by the casting pressure and difference of casting molds. This opinion corresponded with the present one. Castability was affected by the casting mold used even in the same casting conditions. For the purpose of equaliz-

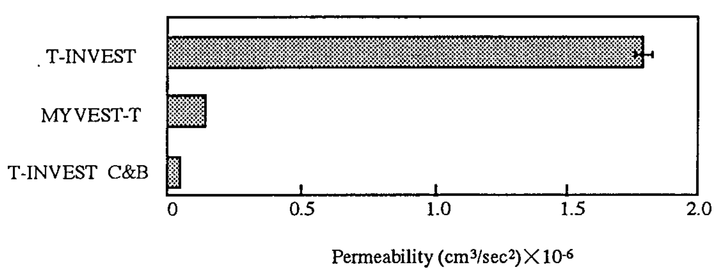

Fig. 6: Permeability of three different molds

Table 5: Analysis of variance on sprue and pressure and investment

Source	Sum of squares	Degrees of freedom	Mean square	F value	Ratio of contribution
A: Sprue	130269.00	2	65134.300	272.07*	57.26
B: Pressure	24219.90	3	8073.300	33.72*	10.35
C: Investment	3081.01	2	1540.510	6.43*	1.14
A×B	7963.91	6	1327.320	5.54*	2.85
A×C	11504.20	4	2876.040	12.01*	4.63
B×C	10250.30	6	1708.390	7.14*	3.86
A×B×C	4853.65	12	404.471	1.69	0.00
Error	34473.50	144	239.399		19.91
Total	226615.00	179			100.00

*P<0.01

ing the conditions, 3 types of phosphate bonded casting molds are tested in the present study. Differences of the binders in composition and weight ratios of various compounds should be evaluated for gas outbreaks due to the casting mold[9]. It was confirmed that the castability in pure titanium was affected by the casting pressure and the permeability of casting molds. It was strongly suggested that the sprue diameter was a positive factor for high performance of castability.

In conclusion : In this present study we analyzed the external defects of castings calculating the castability with mesh grid patterns produced with 3 different kinds of phosphate bonded casting molds with the parameters of sprue diameter and casting pressure. The following conclusions were established :

1. Castability with pure titanium was affected by the parameters of sprue diameter, casting pressure and the difference of casting molds. Among them the sprue condition had the greatest influence.
2. In the all directional pressure type casting machine, 2 types of casting molds were observed, one was strongly affected by the casting pressure in castability and the other was scarcely affected by the casting pressure. The former type of casting mold had a low permeability.

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抄録：純チタンの鋳造性に関する研究（第3報）
鋳造圧およびスプルー径がチタンの鋳込率に及ぼす影響について

米田隆紀，黒岩昭弘，五十嵐順正，大野孝文，
関口祐司，井上義久，御郷信也（松本歯大・歯科補綴Ｉ）

本研究の目的は全方向加圧型鋳造機を用いて，スプルー径および鋳造圧の違がチタンの鋳込率に及ぼす影響について比較検討を行うことである．埋没材は通気性の異なる3種類のリン酸塩系埋没材“T-INVEST”，“T-INVEST C&B”，“MYVEST-T”を使用した．鋳造条件としてスプルー径は0.88mm，1.26mm，2.11mm，鋳造圧は2 kgf/cm^2，4 kgf/cm^2，6 kgf/cm^2，8 kgf/cm^{2}として比較検討を行った．その結果，スプルー径が増加すると高い鋳込率が得られた．また，通気性の高い埋没材では鋳造圧の影

響は少なく，通気性の低い埋没材では鋳造圧が増加すると高い鋳込率が得られた．3元配置分散分析よりスプルー径，鋳造圧，埋没材の違いはチタンの鋳込率に影響を及ぼし，最も大きい因子はスプルー径であった．以上の結果から全方向加圧型鋳造機にてチタン鋳造を行った場合，スプルー径が増加すれば高い鋳込率が得られ，通気性が低い埋没材ほど鋳造圧が増加すれば高い鋳込率が得られることが示唆された．