INFLUENCE OF CERAMIC MOLDS PARAMETERS ON THE QUALITY OF SMALL-SCALE CASTS PRODUCED BY THE INVESTMENT CASTING

DYDAK Artur[1], KURDZIEL Piotr[1], ZABA Krzysztof[2], PUCHLERSKA Sandra[2], SZWACHTA Grzegorz[2]

[1] *The Specodlew Enterprise of Foundry Innovation Ltd., Skawina, Poland, EU, artur.dydak@specodlew.com.pl*

[2] *AGH University of Science and Technology, Cracow, Poland, EU, krzyzaba@agh.edu.pl*

Abstract

The paper presents the influence of ceramic molds manufacturing parameters on the quality of small-scale castings produced by the lost wax method. Seven ceramic coatings were applied to the prepared model kits. Three kinds of binders (LUDOX aqueous, hydrolysed ethyl silicate, Remasol water binder) and two types of molding sands (quartz and molochite) were used as ceramic material. Three types of ceramic molds were made: LUDOX ceramic/hydrolysed ethyl silicate and quartz, LUDOX ceramic/hydrolysed ethyl silicate and molochite, Remasol ceramic and quartz. After applying all of the coats, the ceramic form was dried under constant humidity and temperature conditions. Finished ceramic molds were casted with high alloy steels. Roughness tests of wax models, the first ceramic coat, initial shot blasting, sanding, and final shot blasting were performed. The results are presented in form of graphs, tables and pictures.

Keywords: Ceramic molds, investment casting, lost-wax, roughness, cast steel

1. INTRODUCTION

Parts of jet engines with complex geometric shapes (such as low and high pressure turbine blades) [1] are critical for flight safety. They are produced by the investment casting method [2-5]. The main unit processes include production of a wax model, a wax model kit, and multilayer ceramic mold, and wax melting, molding, liquid metal casting, post-processing and quality control.

Commercial software programs such as MAGMASOFT®, ProCAST®, Solid/FlowCAST® and author programs [6-7] are used to support the design of casting processes. This type of software is able to simulate the flow of metal in the mold while priming on the basis of the model kit image.

Quality of precision casting surfaces, defined by the roughness, the presence of foundry defects and the different chemical compositions in relation to interior areas, mainly depends on the phenomena on the boundary of the ceramic form - liquid metal, from the time the mold is submerged to the solidification of the casting. Such processes may be of a thermal or thermo-chemical nature if they are present at the surface of the mold and in the liquid phase of components with high chemical activity.

One of the key parameters is the quality of the surface of the castings, which is a resultant of parameters of the production of the wax model, the mold and the mechanical processing of the castings of the cast.

The purpose of the paper is quantitative analysis of the influence of manufacturing and processing parameters on the surface roughness of the wax model, the first ceramic coat and the surface of castings in the form of the blades after initial shot blasting, sanding and final shot blasting.

2. METHODOLOGY

Wax models, model sets, molds and castings were manufactured under industrial conditions.

For the production of wax casting models (**Figure 1a**) KC 4017B casting wax from Kindt-Collins Company LLC company was used. Single models were combined into model kits (**Figure 1b**), where ceramic molds were made, consisting of 7 coatings, differing in components according to the following specifications:

- Ludox binder, hydrolysed ethyl silicate with quartz flour, sprinkles - quartz sand of different grains, designated 1 (**Figure 1c**),
- Ludox binder, hydrolysed ethyl silicate with molochite powder, sprinkles - molochite sand of different grains, labeled as 2 (**Figure 1d**)
- Remasol binder with quartz flour, sprinkles - quartz sand of various grain size, labeled 3 (**Figure 1e**).

a) b) c) d) e)

Figure 1 Wax model of blade (a), model set (b), form 1 (c), form 2 (d), form 3 (e)

Subsequently, the molds were coated with chromium-nickel steels of grade 1.4825, with a content of about 18 % Cr, 9 % Ni, 0.2 % C and 2 % Si. Once the metal is solidified, the molds are being broken (**Figure 2**).

a) b) c)

Figure 2 Ceramic form after breaking down. A model shell (a), further molds (b-c)

Then, single castings of the blades were cut off from the flood system and subjected to post-processing. Initial shot blasting (**Figure 3**) was made using a S280 spherical shotgun with a size of about 0.3-0.6 mm and a hardness of about 500 HV.

a) b) c) d)

Figure 3 Blade 1 (a), 2 (b), 3 (c) after initial shot blasting and shot (d)

Sanding (**Figure 4**) was made using an electrolyte with a Mohs hardness of 9 and grain size of 0.2-0.5 mm.

a) b) c) d)

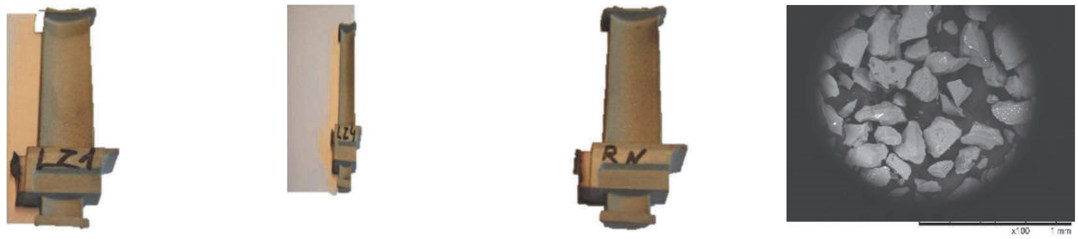


Figure 4 The blade 1 (a), 2 (b), 3 (c) after the sanding process and the electrolyte (d)

For the final shot blasting (**Figure 5**) Chronital was used with a hardness of about 450 HV and a grain size of 0.15-0.5 mm.

a) b) c) d)

Figure 5 Blades 1 (a), 2 (b), 3 (c) after the final blast process and chronital (d)

The evaluation of the surface quality of the wax model, the first ceramic coat before and after casting and casting, prior to mechanical treatment and after shot blasting, sanding and final shot blasting were performed on the basis of roughness measurements, expressed by parameters [8]:

- The Ra parameter is the average measure of the maximum surface roughness
- The Rt parameter is the total height of the profile: the sum of the height of the highest elevation of the profile and the greatest depth of the profile depression within the measuring section is very sensitive to single vertices and recesses
- The Rq parameter is statistically equal to the standard deviation of the ordinate profile, and the single high elevations and recesses of the profile affect its value more than Ra,
- The Rz parameter is the sum of the highest elevation and the largest recess within the elementary section

Measurements were made using an optical profilometer WYKO NT9300 (**Figure 6a**). On each test piece, 5 measurements were taken in the zone shown in **Figure 6b**.

a) b)

Figure 6 Optical profilometer WYKO NT9300

Research results are presented in the form of photographs, tables and graphs.

3. RESULTS

The results of the surface roughness tests of the wax models, the first ceramic coat and the blades of the blades after initial shot blasting, sanding and final shot blasting are shown in **Figures 7-11**.

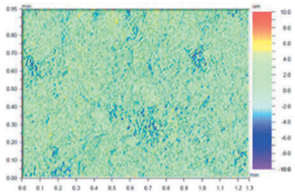
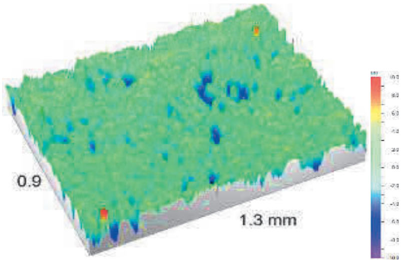
2D topography	3D topography	Roughness parameters [µm]			
		R_a	R_q	R_z	R_t
		2.95	3.99	51.92	73.49

Figure 7 Results of the roughness measurements of the wax blade model

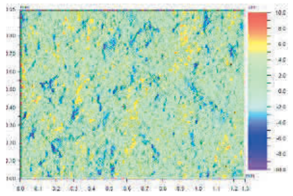
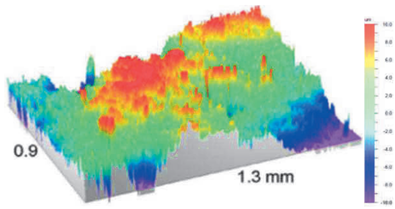
2D topography	3D topography	Roughness parameters [µm]			
		R_a	R_q	R_z	R_t
		First coat (1)			
		6.05	8.58	86.44	110.25
		First coat (2)			
		6.23	9.69	80.22	130.01
		First coat (3)			
		6.71	11.58	87.23	135.45

Figure 8 Results of the roughness measurements of the first ceramic coat

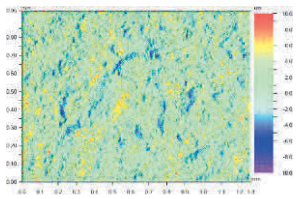
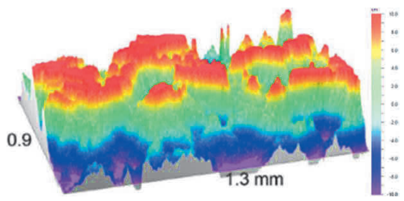
2D topography	3D topography	Roughness parameters [µm]			
		R_a	R_q	R_z	R_t
		Cast (1) after initial shot blasting			
		5.78	7.33	46.23	50.83
		Cast (2) after initial shot blasting			
		6.41	40.03	53.99	61.53
		Cast (3) after initial shot blasting			
		7.13	7.08	49.00	55.22

Figure 9 Results of the roughness measurements after initial shot blasting

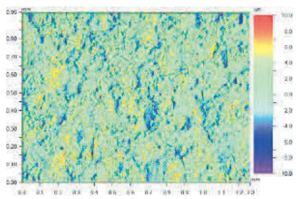
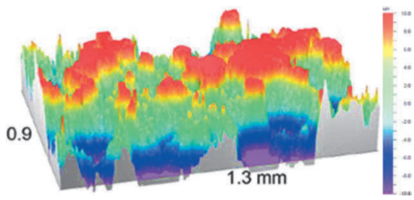
2D topography	3D topography	Roughness parameters [µm]			
		R_a	R_q	R_z	R_t
		Cast (1) after sanding			
		5.28	6.71	49.31	64.02
		Cast (2) after sanding			
		5.87	7.49	51.99	58.07
		Cast (3) after sanding			
		6.48	8.14	61.45	73.12

Figure 10 Results of the roughness measurements after sanding

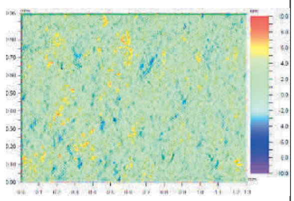
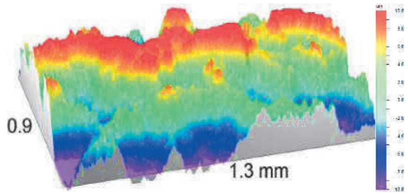
2D topography	3D topography	Roughness parameters [µm]			
		R_a	R_q	R_z	R_t
		Cast (1) after final shot blasting			
		5.10	5.89	40.78	45.98
		Cast (2) after final shot blasting			
		5.59	6.97	41.02	46.82
		Cast (3) after final shot blasting			
		5.83	7.24	44.16	46.76

Figure 11 Results of the roughness measurements after final shot blasting

4. CONCLUSIONS

Based on the result of the research, the following conclusions can be made:

- The wax model has the greatest surface smoothness out of the materials studied.
- The ceramic first coat is approximately 3 times larger than the wax model, with the smallest roughness being variant # 1 made of Ludox binder and quartz molding sand.
- For variants # 2 and # 3 on the casting surface there are residuals of the mold cavity which could be removed only by sanding and final shot blasting.
- The smallest roughness is found after the final shot blasting however the differences are minor with respect to initial shot blasting and sanding.
- In order to obtain a smoother blade surface the process of troweling i.e. vibration treatment using metallic, ceramic or glass materials should be carried out.

ACKNOWLEDGEMENTS

The research was carried out within the framework of the project Applied Research Program No. PBS3 / A5 / 54 / 2016 entitled "Application of Spatial, Optical Digitization, Thermography and Tomography for Technological Assessment of Wax Quality Model Sets and Multilayer Ceramic Molds for Precision Casting of Aircraft Engine Parts" by the National Center for Research and Development.

REFERENCES

[1] PRATT & WHITNEY JT3D. JT8D. JT9D ENGINE FAMILIES. [Online] Cirrus Aviation Inc. http://cirrusaviationinc.com/jt8d.htm

[2] *ASM Metals Handbook. "Casting".* ASM International. 2002. 15.

[3] PATTNAIK. S.. KARUNAKAR. B.D.. JHA. P.K. Developments in investment casting process - A review. *Journal of Materials Processing Technology.* 2012. 212. 11. p. 2332-2348.

[4] SABAU. A.S.. VISWANATHAN. S. Material properties for predicting wax pattern dimensions in investment casting. *Materials Science and Engineering.* 2003. A362. p. 125-134.

[5] JONES. S.. YUAN. C. Advances in shell moulding for investment casting. *Journal of Materials Processing Technology*. 2003. 135. p. 258-265

[6] GEBELIN. J.-Ch.. JOLLY. M.R. Modelling of the investment casting process. *Journal of Materials Processing Technology*. 2003. 135. strony 291-300

[7] HOJNY. M.. GLOWACKI. M. Computer modeling of deformation of steel samples with mushy zone. *Steel Research International*. 2008. vol. 79. no. 11. pp. 868-874.

[8] ISO 4287:1997/Cor.1:1998/Cor.2/2005