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EXPERIMENTAL STUDY ON SUPPORT MATERIAL COMPOSITION FOR SELECTIVE VACUUM MANUFACTURING RP TECHNIQUE

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ABSTRACT: This paper presents a study on the support material compositions for selective vacuum manufacturing, a rapid prototyping technique that creates a physical prototype layer by layer with two conventional manufacturing processes: sand casting and material sintering. Experiments were conducted to identify the amount of cornstarch, reported to be an appropriate binder, mixed in the two types of support material: salt and silica sand. The experimental results recommended the different amount of cornstarch to the two types of the support material.

INTRODUCTION

Since its introduction three decades ago, rapid prototyping (RP) has been well accepted and widely used for creating physical prototypes for many purposes. Several RP techniques have been developed. Some of them (i.e., SLA, SLS, LOM, FDM and 3D printing) are available in the market (Kai & Fai, 2000) and some of them are being developed, including selective vacuum manufacturing (SVM). SVM is an RP technique that creates a prototype layer by layer with two conventional manufacturing processes: sand casting and material sintering. As illustrated in Figure 1, SVM process starts with layering a support material. A cavity profile is then formed by controlling the movement of vacuum head on the support material. Part material is filled into the cavity and sintered. The process is repeated until the prototype is completely built. It has been used to create prototypes from polymer powder (Phattanaphibul & Koomsap, 2009), natural latex (Risdiyono & Koomsap, 2006) and plaster of Paris powder (Senanan et al., 2013).

Figure 1. Steps of SVM technique.

The surface quality of the prototypes is depended upon the quality of the cavity created in the support material. With the initial purpose for manufacturing application, silica sand was selected for support material. Silica sand mixed with bentonite 2 wt% of silica sand and water 4 wt% of

silica sand was recommended (Risdiyono & Koomsap, 2006). Later on, salt was introduced in order to apply SVM in medical application because it is easy to reduce its grain size by mechanical grinding, and to remove by dissolving with water and leaving no residue on a constructed part. Pure salt, however, cannot provide the good cavity because it lacks of cohesive force. Therefore, flour was applied as a binder (Phattanaphibul & Koomsap, 2010). The study has been extended to the effect of different types of flour on cavity forming. Tempura flour, constarch, rice flour, tapioca flour and glutinous rice flour were studied. The results indicated that the support material with cornstarch as the binder outperformed the others (Janokul et al., 2012). The cavity had smooth surface, and sharp and striaght edges. Recently, researchers have reported that cornstarch was also a suitable binder for silica sand (Thamnitatsana et al., 2014). The quality of the cavities created in the mix of silica sand and cornstarch was better than the original mix with bentonite. However, the composition of cornstarch in both types of support material were not reported.

Presented in this paper is a study to determine the suitable compositions of the two support materials: salt and silica sand used cornstarch as the binder. Next section presents design of experiment followed by its results and discussions. The conclusion are addressed in the last section.

DESIGN OF EXPERIMENT

Two sets of experiments were conducted in this study. The first experiment was intended to determine the suitable composition of salt mixed with cornstarch and water and the second experiment was designed to determine the appropriate composition of silica sand mixed with cornstarch and water. For the first experiment, the amount of cornstarch and the amount of water were varied five levels from 1 wt% to 5 wt% of salt. For the second experiment, the amount of cornstarch was varied five levels from 1 wt% to 5 wt% of silica sand and the amount of water was varied three levels from 1 wt% to 3 wt% of silica sand because the cavity could not be formed when the amount of water was more than 3 wt% of silica sand for all levels of the amount of cornstarch as shown in Figure 2.

Figure 2. Cavity used the amount of water (more than 3 wt% of silica sand).

In this study, the particle sizes of salt and silica sand were controlled between 52 and 76 μm by grinding process and screening with a 200×200 meshes sieve. The particle sizes of cornstarch were controlled between 45 and 51 μm by screening through a 250×250 meshes sieve. Salt was mixed with cornstarch before adding water. For each combination, after the support material was prepared, five straight line cavities were created by moving the nozzle tip with 0.5 mm depth into the support material. The surface quality of the created cavities was observed and the top views of the cavities were then captured by a camera for further evaluation.

Two criteria for evaluation were sharpness and straightness of edges. The edge sharpness was checked by visual inspection and the edge straightness was checked by measurement inspection. To determine edge straightness, the distances between the edge of the known cavity and the edge of the created cavity were randomly measured on both edges. To measure these distances, Adobe Photoshop CS5 program was applied to convert the captured images to be grayscale images. Five distances were measured on each edge. Their standard deviations were calculated for all edges to determine the edge straightness.

RESULTS AND DISCUSSION

Support material composition for salt

Table 1 illustrates the experimental results of the created cavity and edge straightness for salt. From top view observation, the cavities that were made from all levels of cornstarch with water 1 wt% of salt had sharp edges. The humidity made the support material to be difficult to be removed. As the result, the cavities had blur edges when the amount of water was increased.

Table 1. Experimental results of the created cavities of salt and edge straightness for salt.

		The amount of cornstarch (wt% of salt)									
		1		2		3		4		5	
		Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)
The amount of water (wt% of salt)	1		0.2176		0.1591		0.1693		0.1471		0.2182
		0.1091		0.1172		0.0794		0.1756		0.1815
		0.3444		0.1378		0.2012		0.1425		0.1205
		0.2591		0.1203		0.3129		0.1851		0.1886
		0.2781		0.1029		0.2615		0.3549		0.2819
		Avg.	0.2417	Avg.	0.1275	Avg.	0.2049	Avg.	0.2010	Avg.	0.1981
	2		0.1378		0.2229		0.2058		0.1842		0.2514
		0.2306		0.1256		0.1192		0.1378		0.1769
		0.1630		2.4226		0.1192		0.1515		0.1784
		0.2249		0.1858		0.1369		0.2461		0.1549
		0.2545		0.1330		0.1709		0.3232		0.1739
		Avg.	0.2022	Avg.	0.6180	Avg.	0.1504	Avg.	0.2086	Avg.	0.1871
	3		1.5940		0.2265		0.2748		0.1900		0.2053
		1.4578		0.2772		0.0973		0.1414		0.2091
		0.9715		0.2610		0.2328		0.3212		0.2434
		1.2272		0.2772		0.2947		0.1279		0.2272
		0.5597		0.1806		0.2128		0.2001		0.1591
		Avg.	1.1620	Avg.	0.2445	Avg.	0.2225	Avg.	0.1961	Avg.	0.2088
	4		0.3051		0.2189		0.1515		0.4457		0.0973
		0.1100		0.1425		0.1934		0.2576		0.4119
			0.1581		0.1317		0.2407		0.3776		0.3057
			0.2212		0.1549		0.2715		0.2066		0.1471
			0.2293		0.1369		0.2139		0.1269		0.2058
		Avg.	0.2047	Avg.	0.1570	Avg.	0.2142	Avg.	0.2829	Avg.	0.2336
	5		0.1856		0.1227		0.3386		0.2626		0.0892
			0.0973		0.1622		0.1583		0.2114		0.1214
			0.0903		0.3517		0.3162		0.3568		0.1709
			0.1748		0.2322		0.1919		0.2790		0.1865
			0.1547		0.2001		0.1100		0.2714		0.1317
		Avg.	0.1405	Avg.	0.2138	Avg.	0.2230	Avg.	0.2762	Avg.	0.1399

For straightness evaluation, standard deviations were calculated for all edges of all cavities. The average standard deviations representing edge straightness errors on all cavities are presented in Table 1. The results indicate that the cavities made from the amount of cornstarch (2 wt% of salt) and the amount of water (1 wt% of salt) had the straightest edges and less variability as shown in Figure 3a.

ANOVA then was applied to determine the influence of cornstarch and water on the surface quality of the cavity. In Figure 3b, the ANOVA results show that at 95% of confidence interval both factors, especially water, had the significant effect on the quality of the cavity. According to the criteria, salt with cornstarch 2 wt% of salt and water 1 wt% of salt has been recommended to be the composition of the support material for SVM rapid prototyping in medical application.

(a) Boxplot of the edge straightness error

Two-way ANOVA: Data versus water, cornstarch					
Source	DF	SS	MS	F	P
water	4	0.7866	0.196657	3.76	0.007
cornstarch	4	0.6374	0.159345	3.05	0.020
Interaction	16	3.8316	0.239472	4.58	0.000
Error	100	5.2266	0.052266		
Total	124	10.4822			

S = 0.2286 R-Sq = 50.14% R-Sq(adj) = 38.17%

(b) ANOVA result of the edge straightness error

Figure 3. boxplot and ANOVA result of the edge straightness for salt.

Support material composition for silica sand

Table 2 illustrates the experimental results of the created cavity and edge straightness of silica sand. From top view observation, the cavities that were made from three compositions (cornstarch 2 wt% of silica sand and water 1 wt% of silica sand; cornstarch 3 wt% of silica sand and water 1 wt% of silica sand; and cornstarch 3 wt% of silica sand and water 2 wt% of silica sand) had sharp edges. When the amount of water was increased, the support material was difficult to be removed. As the result, the cavities had blur edges.

For straightness evaluation, standard deviations were calculated for all edges of all cavities. The average standard deviations representing edge straightness errors on all cavities are presented in

Table 2. The results show that the cavities made from the amount of cornstarch (3 wt% of salt) and the amount of water (2 wt% of salt) had the straight edges and less variability as shown in Figure 4a.

Similarly, ANOVA was applied to determine the effect of cornstarch and water on the quality of the cavity. In Figure 4b, at 95% of confidence interval only water had the significant effect on the quality of the cavity. According to the criteria, salt with cornstarch 3 wt% of salt and water 2 wt% of salt has been recommended to be the composition of the support material for SVM rapid prototyping in manufacturing application.

Table 2. Experimental results of the created cavities and edge straightness for silica sand.

		The amount of cornstarch (wt% of silica sand)									
		1		2		3		4		5	
		Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)	Created cavity	Straightness error (mm)
The amount of water (wt% of silica sand)	1		0.2865		0.1194		0.2126		0.1570		0.2065
			0.1964		0.1526		0.2114		0.2096		0.1385
			0.3153		0.1166		0.1819		0.3942		0.1810
			0.1695		0.1301		0.1405		0.1791		0.1982
			0.2061		0.0837		0.1943		0.1216		0.2602
		Avg.	0.2348	Avg.	0.1205	Avg.	0.1881	Avg.	0.2123	Avg.	0.1969
	2		0.2559		0.2871		0.1137		0.3678		0.0953
			0.2362		0.1895		0.0999		0.1828		0.1031
			0.2136		0.2129		0.1159		0.1862		0.1926
			0.2173		0.2072		0.0832		0.1655		0.2823
			0.2763		0.2282		0.1388		0.1606		0.8951
		Avg.	0.2399	Avg.	0.2250	Avg.	0.1103	Avg.	0.2126	Avg.	0.3137
	3		0.5053		0.6604		0.4874		0.1613		0.2168
			0.2119		0.1083		0.5222		0.2221		0.7309
			0.2171		0.3180		0.3415		0.2974		0.1443
			0.2760		0.2202		0.4558		0.2841		0.2462
			0.3396		0.3214		0.1336		0.3473		0.4953
		Avg.	0.3100	Avg.	0.3257	Avg.	0.3881	Avg.	0.2624	Avg.	0.3667

CONCLUSIONS

Experiments were conducted to determine the compositions of the two support materials. The results show that the compositions were different. In case of salt, the suitable composition was salt, cornstarch 2 wt% of salt and water 1 wt% of salt. For silica sand, the suitable composition was silica sand, cornstarch 3 wt% of silica sand and water 2 wt% of silica sand. According to the results, both factors play an important role in the quality of the cavity even though water has the effect more significantly than cornstarch.

(a) Boxplot of the edge straightness error

Two-way ANOVA: Data versus water, cornstarch					
Source	DF	SS	MS	F	P
water	2	0.27227	0.136137	7.13	0.002
cornstarch	4	0.05200	0.013000	0.68	0.608
Interaction	8	0.13985	0.017482	0.92	0.510
Error	60	1.14609	0.019102		
Total	74	1.61022			

S = 0.1382 R-Sq = 28.82% R-Sq(adj) = 12.22%

(b) ANOVA result of the edge straightness error

Figure 4. Boxplot and ANOVA result of the edge straightness for silica sand.

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