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RESEARCH & KNOWLEDGE

Research Article

Cold Spray Parameters for White Portland Cement Coating on Stainless Steel

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Abstract: This research aims to study parameters that affect white Portland cement coating on 316L stainless steel using the cold spray technique in order to achieve 100-150 µm of coating thickness. The evaluation parameters, which were studied are: 1) speed of the sample moving pass through the spray nozzle 2) size of the spray nozzle 3) distance between the coating nozzle and sample surface 4) coating repetition. After the cold spray process, the thickness of the specimen was analyzed using an optical microscope. From preliminary experiments, the results showed that the nozzle of 1.2 mm with the speed of the sample moving pass through the nozzle of 600 cm/min produced good surface condition and satisfying distribution of coating area on coated sample. In addition, a distance between the nozzle of 20 cm with twice coating times, was the optimum condition created 132 µm of coating thickness of the coated sample.

Keywords: White Portland cement, Stainless steel costing, Cold spray

1. Introduction

The stainless steel grade 316L is material that is widely used in surgery due to its good corrosion resistant and the ability to be compatible with human tissue (Gopi et al, 2013). However, the stainless steels may corrode inside the body under certain circumstances in a highly stressed and oxygen depleted region, such as the contacts under the screws of the bone fracture plate. Therefore, this material is suitable to use only in temporary implant devices. To improve their bioactivity, stainless steel is usually coated with hydroxyapatite (HAp), which has been widely used in medical applications due to their favorable biocompatibility and osteoconductivity (Baptista et al 2016, Dey et al, 2009). Therefore, a bioactive HAp coating on stainless steel surface would be one of the most promising implant materials of a good combination of coating biocompatibility and substrate strength. The plasma spraying is now widely accepted method for HAp coating because it gives tight adhesion between HAp and metal substrate with a coating thickness about 100 to 150 µm. Unfortunately, disadvantages of the plasma spray process are relative high cost and complexity of process. Moreover, the extremely high temperature of plasma spray is cause of decomposition of the coating, instability of coating-substrate interface, thermal expansion mismatch, residual stress in coating layer and unstable duration of coating under body fluids and varying local loading (Ishikawa, et al., 1997; Lu et al, 2004). Therefore, novel cold spray coating is an interesting technology need to be studied to obtain surface coating. This technique may offer several technological advantages over thermal spray, for examples, tensile residual stress, thermal decomposition and instability of coating-substrate interface may be avoided. However, the formation of HAp coating on the metal substrate at low temperature is a limitation. In order to solve this restriction, White Portland cement (WPC) is the prefer choice to study since its setting behavior and strength development are essentially the same as that expected in gray cement. WPC based materials have been proved non-toxic and feasibility of obtaining biocompatibility and bioactivity. It has potential to promote bone healing and bone tissue engineering application. Moreover, WPC has also been proved the feasibility of obtaining bioactivity for bone tissue engineering application (Chaipanich and Torkittikul, 2011; Gallego, et al. 2008; Coleman, et al. 2007; Abdullah, et al. 2002; Torkittikul and Chaipanich, 2009; Torkittikul and Chaipanich, 2012; Pangdaeng et al., 2015.). In addition, white color of WPC seems to be suitable source material for bone substitute materials.

The principal objective of this study to develop the novel spray tool and process of WPC coating on stainless-steel substrate and to evaluate the optimum parameters to achieve the coating thickness at 100 - 150 µm. The evaluation parameters, which were studied are: 1) spray nozzle size 2) speed of the sample moving pass through the spray nozzle 3) distances between coating nozzle and sample surface 4) coating repetition.

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2. Materials and Methods

2.1 Materials preparation

The materials used in the research are stainless steel 316L (SUS 316L) plate and commercial grade white Portland cement (WPC). The chemical composition of WPC is shown in Table 1. The SUS 316L plate was cut to a shape of rectangular with a size of 10x20x3 mm. They were then sand-blasted in order to get average roughness (Ra) of 3-6 μm (Dey et al, 2009). The blasted plates were then washed in acetone for 30 minutes using ultrasonic machine to remove grease and remaining sand on the samples. The WPC powder was sifted through a 100-mesh screen and then mixed with distilled water at a ratio of 1: 0.5 by weight before spraying.

2.2 Spray coating parameters and sample preparation

Figure 1 shows schematic design of cold spray coating equipment, which is compose of: 1) air compressor 2) spray gun with three different sizes of nozzle and 3) coating table, which can adjust the speed of sample moving and coating distance. In this study, four spraying parameters were selected to study the suitable coating condition for achieving optimum coating thickness of 100-150 μm, as follow: 1) sizes of the spray nozzle of 1.2, 1.7 and 2.0 mm. 2) speeds of sample moving pass through the spray nozzle of 600, 1,200 and 1,800 cm/min 3) distances between the spray nozzle and sample of 15, 20, 25 and 30 cm. and 4) coating repetition of 1, 2 and 3 times. For each condition, the air pressure from compressor was fix at appropriate pressure of 0.3 MPa.

Table. 1 Elements of Portland Cement White. (Pangdaeng et al., 2015.)

Material	Chemical composition (%)							
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	SO_3	TiO
WPC	14.68	1.93	78.77	0.33	0.31	0.04	3.22	0.12

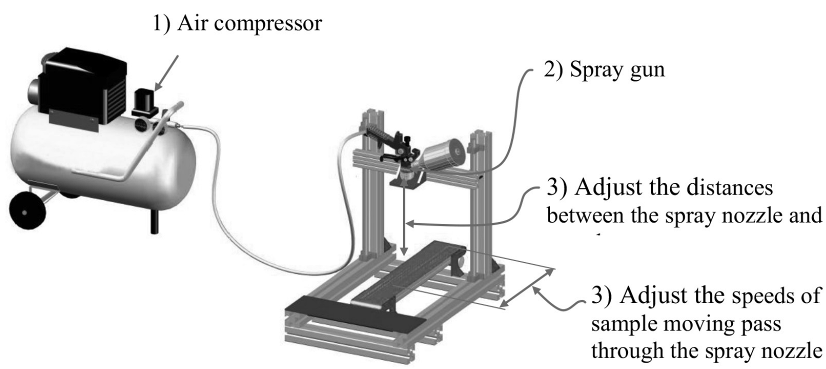


Fig. 1 Schematic design of cold spray coating equipment

After spraying, the coated samples were leaved at ambient temperature for 1 hour and cured in water for 24 hours to allow the coating layer setting. The coated samples were then mounted into resin and allowed them to solidify at room temperature for 24 hours. The mounted samples were polished with sandpaper and diamond powder to get the mirror surface. The coating thickness was examined by measuring average thickness from 5 points using an optical microscope (OM), as shown in Fig 2.

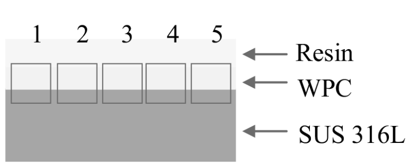


Fig. 2 Measuring points of the coating thickness of the sample

3. Results and discussion

3.1 The size of the spray nozzle and moving speed of sample pass through the spray nozzle

In order to find the proper size of spray nozzle, the air pressure from compressor and the spraying distance were controlled at 0.3 MPa and 20 mm, respectively. The SUS 316L substrate was not moved. The three diameter sizes of the spray nozzle, 1.2, 1.7 and 2.0 mm were selected to evaluate the appropriate spraying area. After selected a proper nozzle size, the three moving speeds of sample, 600, 1,200 and 1,800 cm/min were selected to evaluate the good speed condition for spraying.

Figures 3 and 4 show the schematic of the distribution of spray area and the coated surface of specimens from different size of nozzle, respectively. From the results, they were found that the size of 1.2 mm diameter of the spray nozzle created the suitable spraying area and the uniform coating surface on the SUS 316L substrate. The nozzle size of 1.2 mm then was used to determine the suitable moving speeds of sample. Coated surfaces of samples from different moving speed are presented in Fig. 5. The coating speed of 600 cm/min condition shows the good result of the surface of coating according to the smooth and uniformity of the coated surface.

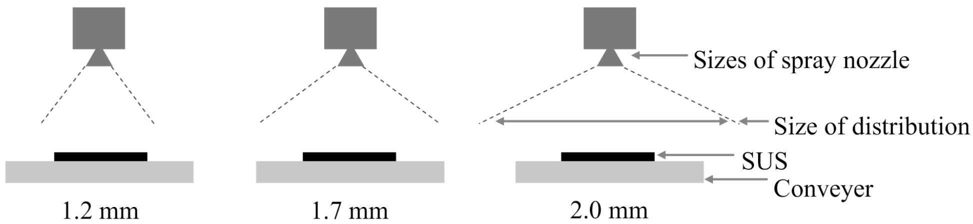
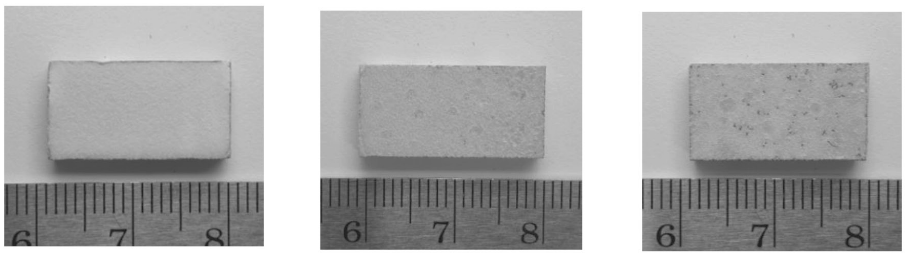


Fig.3 The distribution of spray area from different size of nozzle



1.2 mm 1.7 mm 2.0 mm

Fig. 4 Coating surface of different size of the spray nozzle.

600 cm/min 1200 cm/min 1800 cm/min

Fig. 5 Coated surface of samples from different moving speed pass through the spray nozzle

3.2 The coating distances between spray nozzle and sample and the coating repetition

Other two parameters that might affect the coating thickness are the coating distance between spray nozzle and sample and the coating repetition. The coating distance of 15, 20, 25 and 30 cm and the coating repetition of 1, 2 and 3 times were selected to conduct. The 100-150 µm coating thickness is the target of this study.

Figures 6-9 show the profiles of the coating thickness along the samples after sprayed on the SUS substrate with different coating distance and repetition. The coating thickness was increased with increasing coating repetition for all coating distance. The coating distance of 15 cm shows a bit over target result after the first time of coating, as shown in Fig. 6.

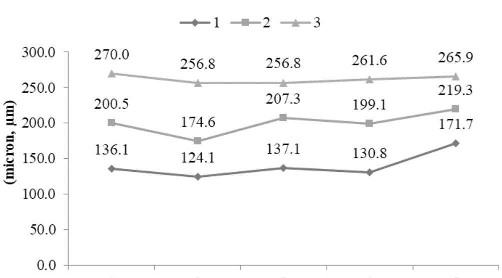


Fig. 6 Coating thickness of samples after sprayed with a coating distances of 15 cm and repetition of 1, 2 and 3 times

The optimum parameters to achieve the coating target were the coating distance of 20 and 25 cm with the repetition for 1-2 times, as shown in Figs. 7 and 8.

From the result in Fig. 9, the optimum coating thickness form these conditions (30 cm coating distance, 1-3 spray repetition) was not success.

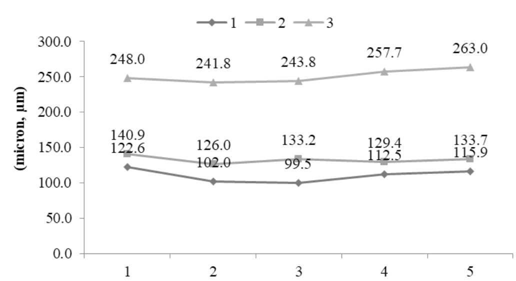


Fig. 7 Coating thickness of samples after sprayed with a coating distances of 20 cm and repetition of 1, 2 and 3 times

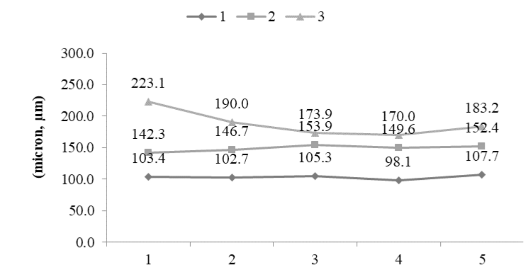


Fig 8. Coating thickness of samples after sprayed with a coating distances of 25 cm and repetition of 1, 2 and 3 times.

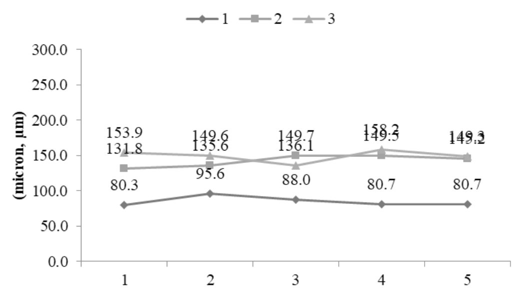


Fig 9. Coating thickness of samples after sprayed with a coating distances of 30 cm and repetition of 1, 2 and 3 times.

The coating thickness results of each coating condition were summarized in Table 2. From the desired thickness of 100-150 μm, the conditions that can be used for preparing the WPC coating sample are as follow: 1. the coating distance of 15 cm and repetition of 1 time (average coating thickness, 139 μm). 2. The coating distance of 20 cm and repetition of 1 and 2 times (average coating thickness, 110 and 132 μm respectively). 3. The coating distance of 25 cm and repetition 1 time (average coating thickness, 103 μm). 4. The coating distance of 30 cm and repetition 2 times (average coating thickness, 142 μm)

From the observation on the coated sample sprayed with the coating distance of 15 and 30 cm, the coating surfaces were not be uniform. On the other hand, the samples from the coating distance of 20 and 25 cm, the surface of the sprayed samples was completion and more consistency when compared to those sprayed with the coating distance of 15 and 30 cm. Figure 10 shows the coating layer of the sample coated from the coating distance of 20 cm with 2 times repetition.

4. Conclusion

The cold spray and processes of WPC coating on stainless-steel substrate were developed. The optimum parameters to achieve the coating thickness of 100-150 μm were summarized as follow:

Table 2 The coating thickness results from each coating condition

Distance	Repetition	Point of measuring thickness					Mean
		1	2	3	4	5	
30	1	80.3	95.6	88.0	80.7	80.7	85.1
	2	131.8	135.6	149.7	149.5	145.2	142.4
	3	153.9	149.6	136.1	158.2	149.3	149.4
25	1	103.4	102.7	105.3	98.1	107.7	103.4
	2	142.3	146.7	153.9	149.6	152.4	149.0
	3	223.1	190.0	173.9	170.0	183.2	188.0
20	1	122.6	102.0	99.5	112.5	115.9	110.5
	2	140.9	126.0	133.2	129.4	133.7	132.6
	3	248.0	241.8	243.8	257.7	263.0	250.9
15	1	136.1	124.1	137.1	130.8	171.7	139.9
	2	200.5	174.6	207.3	199.1	219.3	200.1
	3	270.0	256.8	256.8	261.6	265.9	262.2

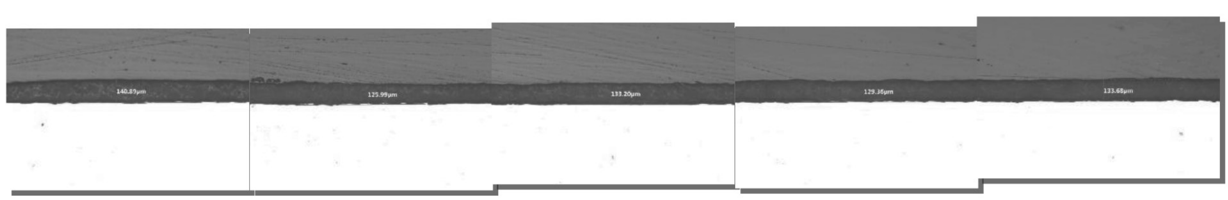


Fig 10. The coating layer of the sample coated from the coating distance of 20 cm with 2 times repetition

1. The nozzle size of 1.2 mm and coating speed of 600 cm/min created the suitable distribution of spray area with uniform coating surface on the SUS substrate.

2. The optimum parameters to achieve the coating target were the coating distance of 20 and 25 cm with the repetition for 2-3 times. The coating distance of 20 cm with 2 times repetition has an average thickness 132µm which is the desired thickness range (100-150µm).

3. The coating thickness increased with decreasing the coating distance and increasing the spraying repletion.

5. Acknowledgement

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