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Influence of Processing Conditions on the Thermal Spraying Coating †

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Abstract

The mechanical properties of 80%Ni-20%Cr alloy sprayed at each spraying condition are investigated by means of tensile strength test and Arata Coating Test with Jet Particles. The relation between the microstructure and the properties of the sprayed coatings are examined. Moreover, the effect of spraying condition on the mechanical properties was discussed on the basis of the oxidation behaviour during spraying and dynamic behaviour observation of the particles at adhesive stage.

Main conclusion obtained are summarized as follows.

(1) *The favorable mechanical properties of coatings are obtained at the spraying distance of 15 ~ 20 cm and the properties become poor with the increase of spraying distance.*

(2) *The maximum tensile strength at the optimum distance for each spraying material decreases with the increase of particle size.*

(3) *The mechanical properties of coatings may depend greatly on the amount of oxides in coatings formed during spraying.*

(4) *The mechanical properties of coatings are affected by the variation of the spraying angle.*

KEY WORDS: (Flame Spraying) (Tensile Strength) (Spraying Conditions) (Ni-Cr Alloy) (Coating)

1. Introduction

Metallic thermal spraying has been used for many years as a means of improving the resistance of wear, oxidation and corrosion of steel surfaces.[1] However, the influence of spraying conditions such as distance, angle and metal particle size on mechanical properties of sprayed coatings has not been investigated, because the precise test method for coating properties was not well established. If the relation between the these conditions and coating properties make clear, the properties may be improved by obtaining an optimum spraying conditions for producing coatings of a good property.

In this paper, the effect of the above spraying conditions on the mechanical properties of coatings was studied on the basis of coating microstructures and oxidation behavior of particles during spraying.

2. Experimental Procedures

2.1 Thermal spraying methods and materials

80%Ni-20%Cr alloy powders used for spraying in this experiment were all marked and classified into three grade particle sizes, $-145 \sim +170$ mesh ($88 \sim 105\ \mu m$), $-170 \sim +250$ mesh ($62 \sim 88\ \mu m$), $-250 \sim +300$ mesh ($46 \sim 62 \mu m$) and the chemical compositions are shown in **Table 1**. The base material used for thermal sprayed coating are mild steels (SS41) for Arata Coating Test with Jet Particles[2] (ACT-JP) and brass (68%Cu, 0.07 > Pb, 0.05 > Fe, bal. Zn) for tensile strength test. Surface treatment before spraying was carried out under the following conditions; blast powders: angular chilled white iron, ($-24 \sim +32$ mesh) blast pressure: 7.0 kgf/cm^2, bast distance: 20 cm, blast angle: 90°. For metal spraying, the conventional flame spraying method (Metco 5P type) was applied under the following conditions; acetylene gas flow: 980 l/hr, gas pressure: 0.9 kg/cm^2, oxygen gas flow: 1400 l/hr, gas pressure: 1.4 kg/cm^2, spraying distance: 10, 15, 20 and 30 cm. The coating thickness for ACT-JP was 0.4 ± 0.05 mm and for tensile strength test pieces was 2.0 ± 0.2 mm.

2.2 Coating mechanical property tests

The specimen shape and jig for tensile strength test are schematically shown in **Fig. 1**. Tensile tests were performed by an Instron tensile machine using a crosshead speed of 0.5 mm per minute. ACT-JP method is schematically illustrated in **Fig. 2**. The test was evaluated by measuring the weight loss of coatings after the test. ACT-JP was done under the following conditions; jet angle: 35°, jet material: molten alumina ($-35 \sim +60$ mesh), jet distance: 100 mm, jet time: 15 sec, jet air pressure: 4.3 kg/cm^2, nozzle diameter: 5.2 mm. The coating structures were

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Table 1 Chemical composition (wt%) of Ni-Cr alloy powder used.

Ni	Cr	Fe	C	Mn	Si
78.8	19.34	0.34	< 0.01	0.99	0.47

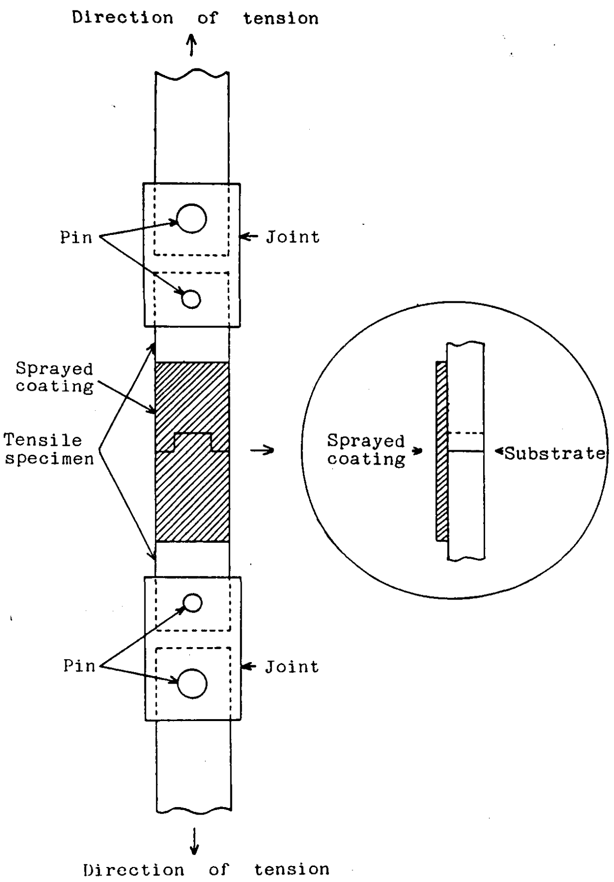

Fig. 1 Schematic diagram of the specimen and jig for tensile strength test.

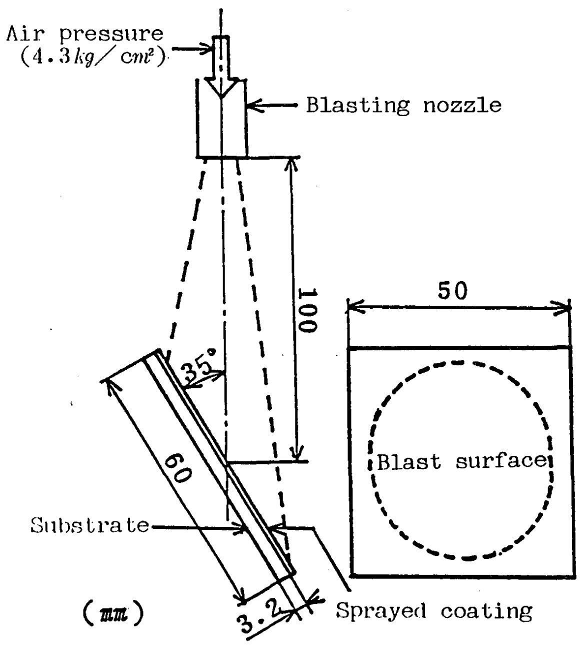

Fig. 2 Schematic diagram of the Arata Coating Test with Jet Particles.

observed by optical and scanning electron microscopies. Measurements of oxide amount in the coatings after spraying was carried out by high temperature oxidation test.[3)]

3. Results and Discussion

3.1 Effect of spraying conditions on mechanical properties

Figure 3 shows the relation between spraying distance and the tensile strength of 80%Ni-20%Cr alloy coatings.

From this figure, the tensile strength of coatings depends greatly on spraying distance. The optimum spraying distance for the tensile strength exists when three spraying particles of different sizes were used. The maximum tensile strength at the optimum distance for each spraying material decreases with the increase of particle size of spraying material. However, at the spraying distance of 30 cm, the tensile strength decreases with the decrease of particle sizes of spraying material.

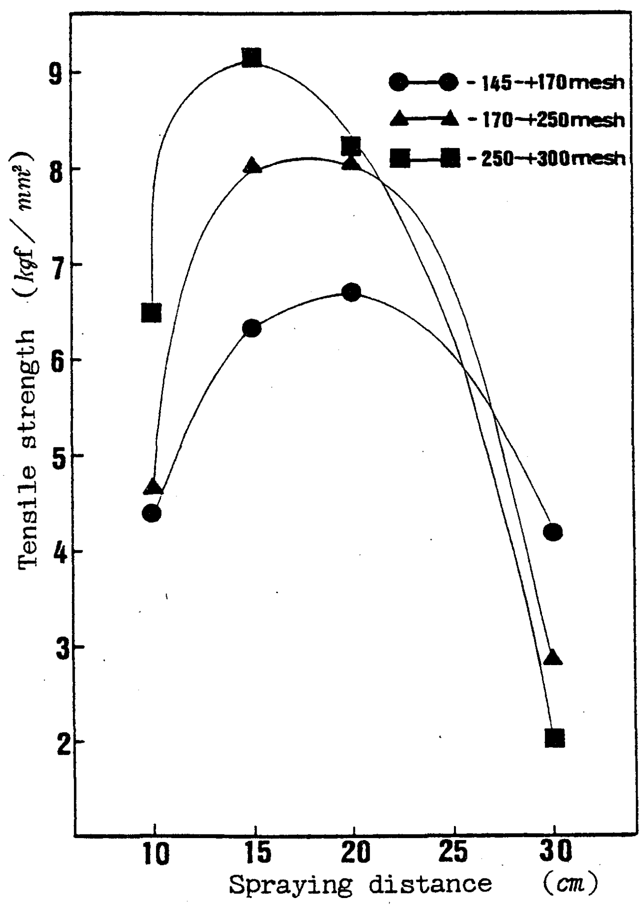

Fig. 3 Relation between spraying distance and the tensile strength of 80%Ni-20%Cr alloy coatings.

The relation between maximum tensile strength (in Fig. 3) and particle size of spraying material is shown in **Fig. 4**. From this figure, the tensile strength increases linealy with the increase of particle size. The similar results of ACT-JP for coatings are shown for the spraying distance in **Fig. 5**. As shown in this figure, ACT values shows similar tendency for spraying distance as tensile strength does. The optimum distance for ACT-JP result, also is seen for each spraying material. At the distance of 30 cm, ACT value increases with decreases of particle size of spraying material.

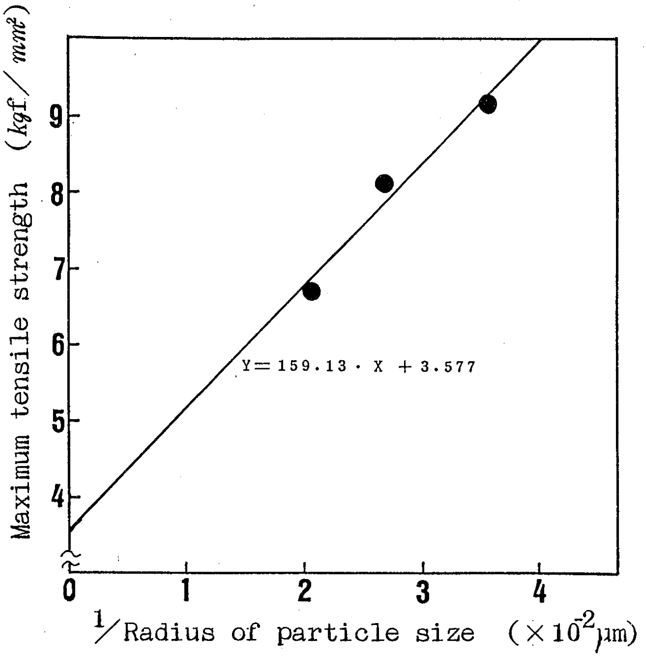

Fig. 4 Relation between the maximum tensile strength and particle size at the optimum spraying distance.

3.2 Effect of spraying condition on coating structure

In order to know the effect of spraying conditions on

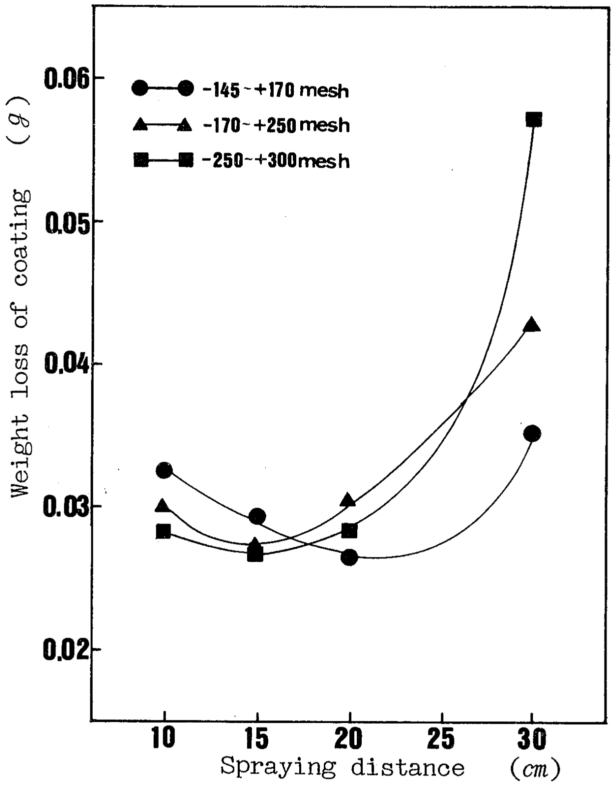

Fig. 5 Relation between ACT-JP values and spraying distance.

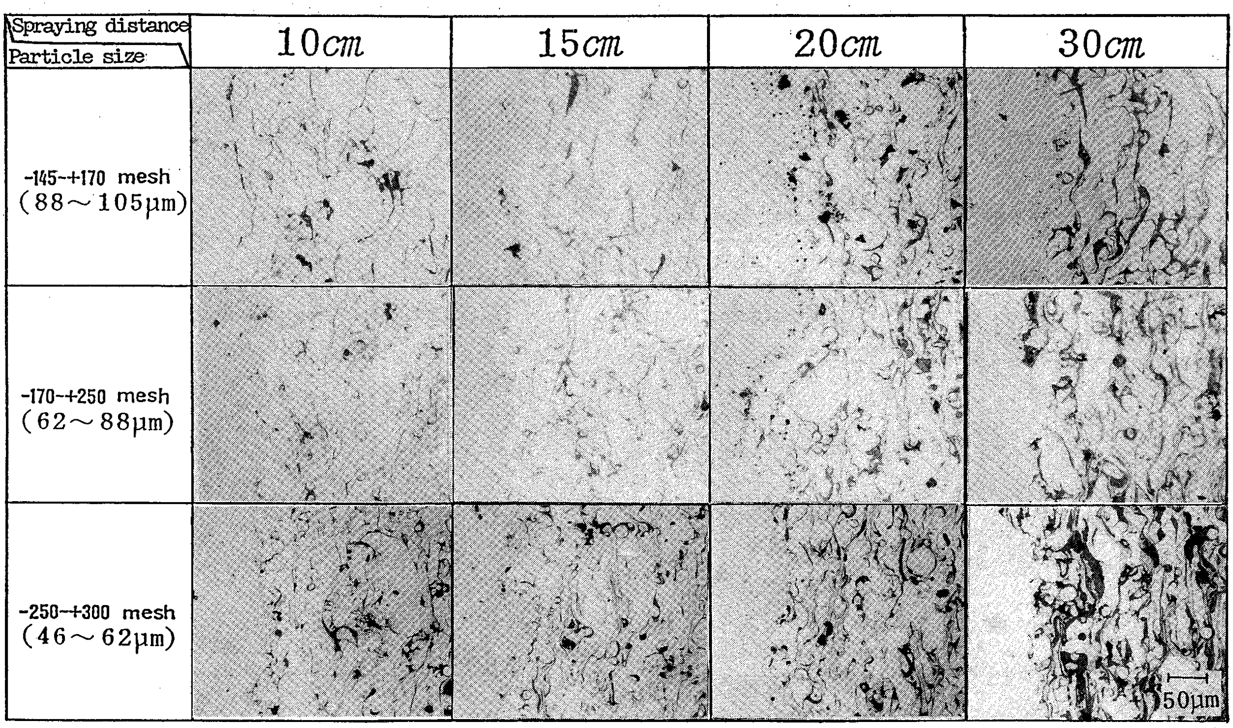

Fig. 6 Change in microstructures of coatings with spraying distance for material of different particle size.

mechanical properties of coatings, the structures of coatings sprayed under various spraying conditions were examined by optical microscope and SEM. The optical microstructures of cross section of coatings are shown with change in spraying distance for each particle size of spraying material in **Fig. 6**. In this figure, there are not clear layer parts (black parts) in coatings sprayed at the distance of 15 ~ 20 cm, where the tensile strength of coatings shows maximum value and ACT value does minimum value for each spraying materials. However, at the spraying distance of 30 cm, the layer structures (black parts) are clearly observed and the fact is more remarkable for smaller particle size. At 10 cm spraying distance, the clear layer structures are not seen but there are non melted particles in coatings of larger spraying particle. The clear layer structure and the existance of non melted particles in coatings may influence greatly on the mechanical properties. Then, the grain boundary parts (black parts in Fig. 6) between packed particles was analyzed by EPMA. The results are shown in **Fig. 7**. From these results, the grain boundary parts (black parts) may be mainly composed of chromium oxide. To verify the fact, the sprayed coating was analyzed by X-ray diffraction. **Figure 8** shows the X-ray diffraction patterns of 80%Ni-20%Cr alloy coatings sprayed at 20 cm of spraying distance with −145 ~ +170 mesh spraying particles. As shown in this figure, it is found that Cr_2O_3 and NiO exists in the coating after spraying.

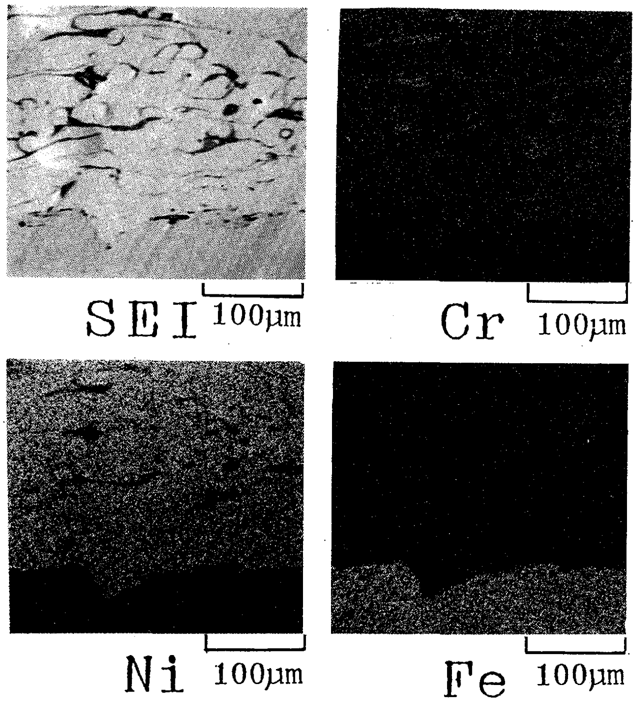

Fig. 7 Secondary electron image and EPMA analysis results of the grain boundary parts.

Figure 9 shows the relation between spraying distance and the amount of oxides in the sprayed coatings. The amount of oxides contained in the coatings was influenced by spraying conditions. Comparired with coatings at spraying distance of 30 cm, oxides amount in coatings sprayed at 10 ~ 20 cm distance is smaller. It may be based on the fact that O_2-C_2H_2 combustion gas stream is not almost contaminated with oxygen gas of outside air during spraying within 20 cm spraying distance. However, at the spraying of 30 cm the gas stream is contaminated with oxygen and the particles are easily oxygenated.

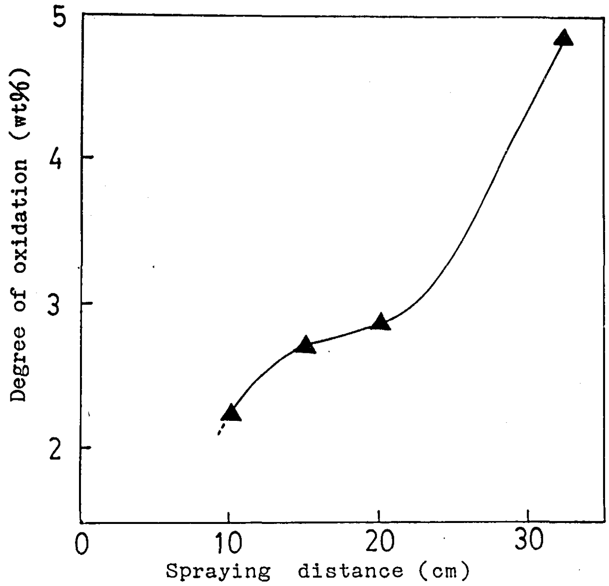

Fig. 9 Relation between oxides amount and spraying distance.

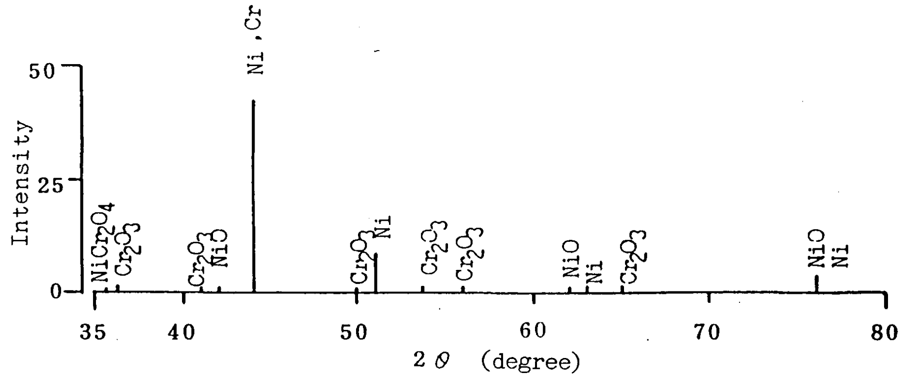

Fig. 8 X-ray diffraction results for flame sprayed coatings.

From figure 3, the tensile strength of coatings showed maximum value at the spraying distance of $15 \sim 20$ cm and decreased with the increase of spraying distance. Also in the ACT-JP, the weight loss of coatings showed minimum value at the same distance ($15 \sim 20$ cm). From oxidation results in Fig. 9, the coatings sprayed at the distance of $15 \sim 20$ cm involve less the oxides such as Cr_2O_3 and NiO than the coatings produced at the distance of 30 cm. From these results, the mechanical properties of coatings may depend greatly on oxides amount in coatings.

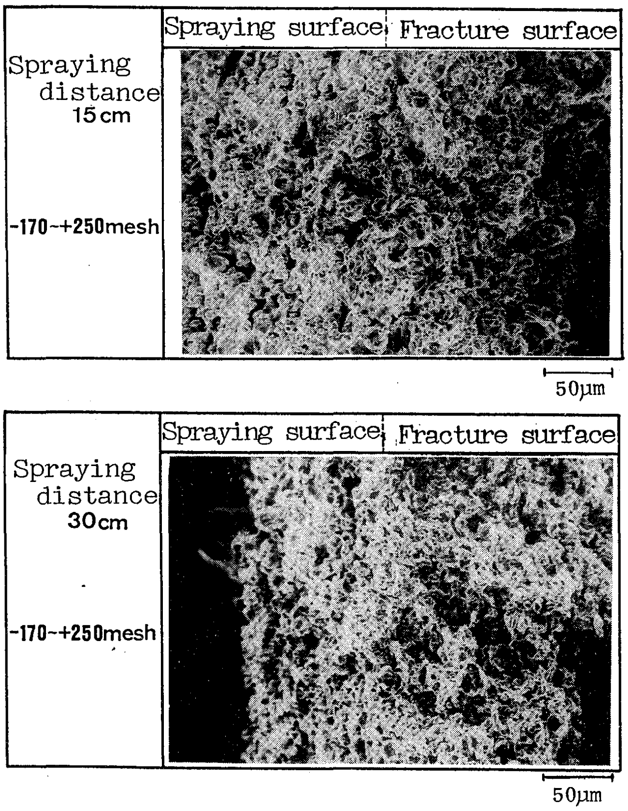

Fig. 10 Typical fracture surface of coatings after tensile test.

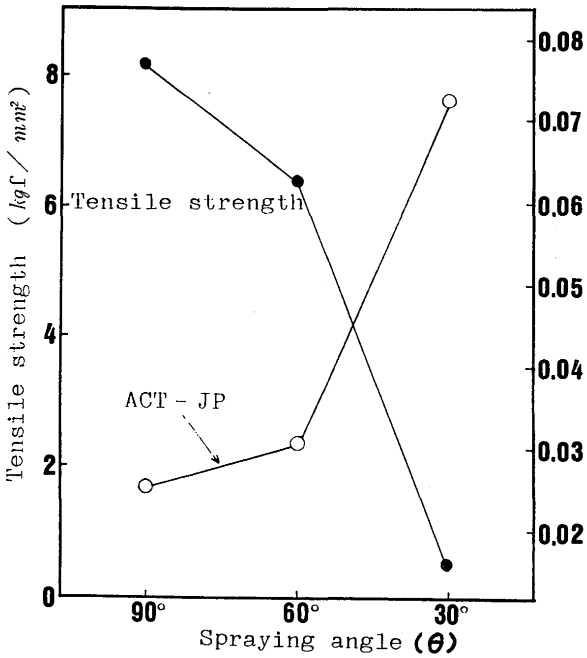

Fig. 11 Effect of spraying angle on the tensile strength and ACT-JP values of coatings ($-145 \sim +170$ mesh) sprayed at the distance of 20 cm.

Figure 10 shows a typical fracture surface of coatings after tensile test and as sprayed surface. From this figure, both surfaces show similar surface states. It is considered that the fracture of coatings occurs mainly at grain boundary parts between packed particles, where oxide compound exists after spraying.

3.3 Effect of spraying angle on properties of coatings

The effect of spraying angle(θ) on the tensile strength and ACT-JP value of coatings sprayed at the spraying distance of 20 cm with particles of $-145 \sim +170$ mesh are shown in **Fig. 11. Figure 12** shows an schematic diagram of spraying method. The tensile strength of coatings increases and the ACT-JP value decreases with the increases of spraying angle (θ).

Figure 13 shows the optical microstructures of cross section of coatings sprayed at each angle. From this figure, it is seen that pores and non bonded parts (black parts) increase at grain boundary parts between particles in coating with the decrease of spraying angle. The such change of microstructures of coatings in spraying angle may influence greatly the mechanical properties. In order to know in detail the relation between the spraying angle and the coating microstructure, the dynamic behaviour of

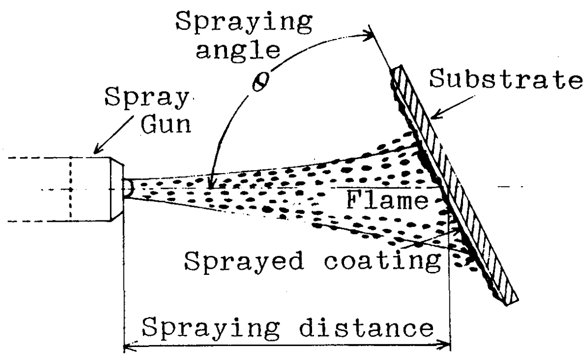

Fig. 12 Schematic diagram of spraying method.

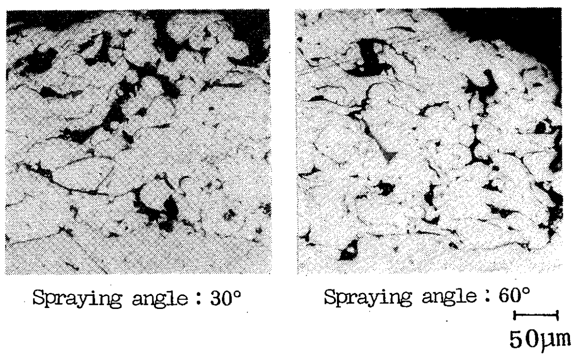

Fig. 13 Microstructures of the cross-section of coatings sprayed at spraying angle of 30° and 60°.

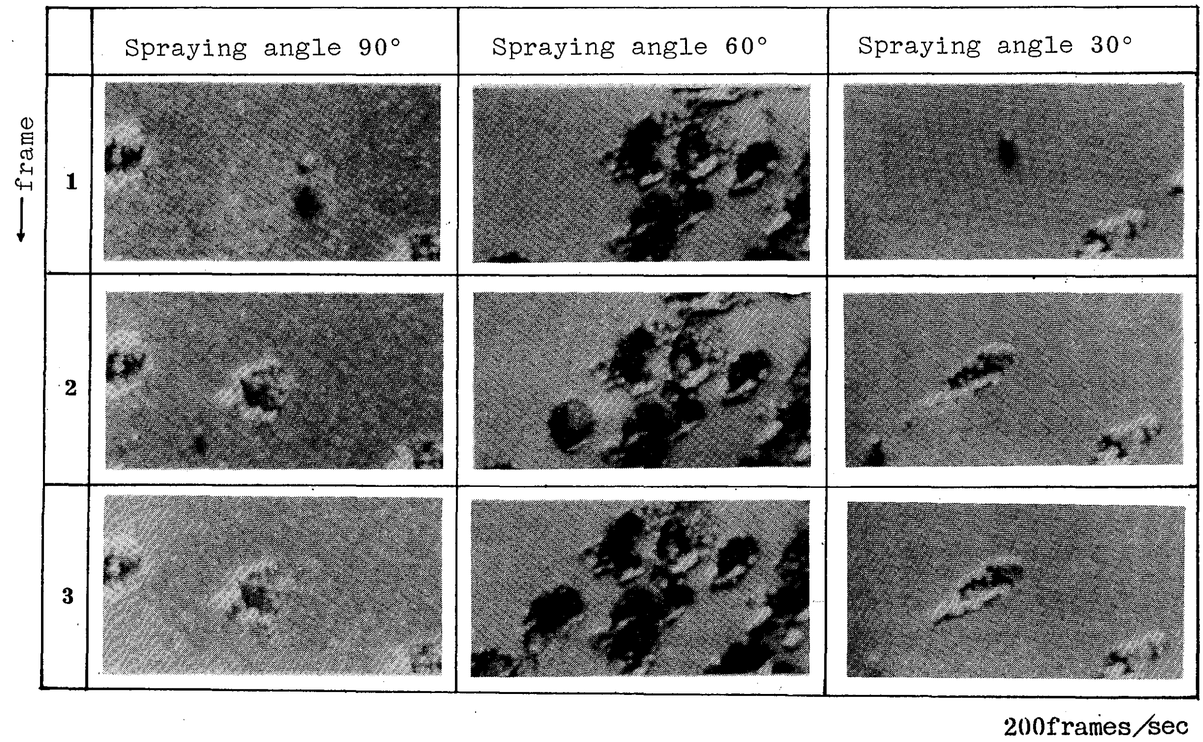

Fig. 14 Dynamic behaviour of spraying particles (Pb) at adhesive stage in each spraying angle.

spraying particles at adhesive stage in variety of spraying angle was observed with high speed video. In this experiment, Pb particles of 775 μm size were used to observe more clearly the behaviour. The results are shown in **Fig. 14.** As shown in Fig. 14, one dimensional flow of one particle on impact stage increases and the bonding strength between particles reduces by the decrease of impact force of vertical direction with the decrease of spraying angle. Therefore, the pores and non bonded part increase in the coatings, so that the mechanical properties decrease.

4. Conclusion

The effect of the spraying conditions such as distance, angle and particle size on the mechanical properties of the sprayed 80%Ni-20%Cr alloy coatings were investigated.

The results obtained are summarized as follows;

1) The favorable mechanical properties (tensile strength, ACT-JP) of coatings are obtained at the spraying distance of 15 ~ 20 cm and the properties become poor with the increase of spraying distance.
2) The maximum tensile strength at the optimum distance for each spraying material decreases with the increase of particle size.
3) The mechanical properties of coatings may depend greatly on the amount of oxides formed during spraying.
4) The mechanical properties of coatings are affected by the variation of the spraying angle.

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