Technical Paper

Development of Parts recycling technology

Toshiyuki Iseki

Masaharu Amano

Komatsu has conducted the "Reman" business which aims to recycle used main components of the construction and mining machinery and sell them as CR (Certified Remanufacturing) units with the quality comparable to those of the new components. Komatsu considers reuse of the parts to be discarded as an important theme in both aspects of machine operating cost and environment preservation. This paper reports the reclamation of worn parts to the specification by arc spray process and the characteristics of sprayed coating as an example of our recycle technologies.

1. Introduction

Komatsu has conducted the "Reman" business which aims to recycle used main components of the construction and mining machinery and sell them as CR (Certified Remanufacturing) units with the quality comparable to those of the new components. In the "Reman" business, not only the materials are reused, the CO_2 discharged during the recycling process can be reduced almost 90%, compared with the manufacture from the raw materials, and that is suitable for environment preservation.

One of the main themes of the "Reman" business is not to discard damaged parts but to repair and reuse them. This paper reports the arc spray process as a technology to restore the dimensions of worn parts.

2. Recycling of Parts by Arc spray process

As an example of worn portions, the worn portion of a shaft fitted with a bearing is shown in **Fig. 1**. The wear may exceed 1 mm. This shaft does not need to be discarded but can be reused, if the dimensions of the worn portion are restored by a build-up process.

Fig. 1 Wear of fitted portion of bearing

As the main techniques of forming thick coating, the build-up welding is compared qualitatively with various thermal spray techniques in **Table 1**. Among these techniques, the arc spray has more advantages than the others and is suitable for restoration of dimensions of worn parts, thus we are promoting its application.

Table 1 Comparison of various repair technologies

		Bond strength	Coating formation speed	Deformation of parts	Structural change of Substrate material	Running cost	Equipment cost
Build-up welding		◎	◎	×	×	◎	◎
Spray	Frame	△	○	◎	◎	○	◎
	Arc	△	◎	◎	◎	◎	◎
	HVOF	○	△	◎	◎	×	△
	Plasma	○	×	○	○	×	×

Superior>◎>○>△>Inferior

The theory of the arc spray process is explained simply below. **Fig. 2** shows the schematic diagram of the arc spray gun, and **Fig. 3** shows the spray of melted metal. In the arc spray process, 2 metallic wires are fed and arc discharge is generated between their tips and they are melted with the discharge energy. The molten material is atomized by compressed air and propelled towards the substrate surface to form a coating continuously.

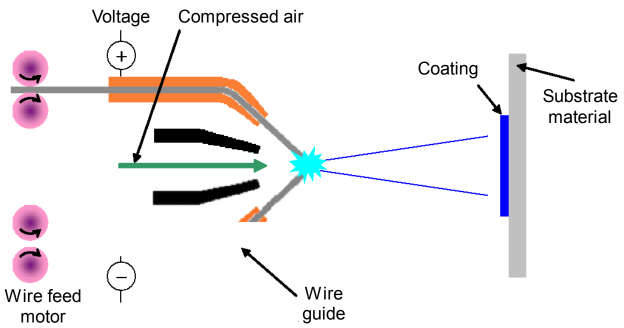


Fig. 2 Schematic diagram of arc spray gun

The general features of the arc spray process are as follows;

Fig. 3 Appearance of arc spray

(1) The spray coating rate per hour is large, thus a coating thicker than 1mm can be formed in a short period
(2) Any material that is electrically conductive can be available
(3) Since wires are used as the material for spray, the material cost is lower than the powder material
(4) Since the parts are less affected by heat, they change less in shape and properties
(5) Since the material is sprayed with electricity and air, the running cost is low
(6) The facility cost is low

3. Parts recycle process

The parts are recycled by the arc spray process according to the flow shown in **Fig. 4**. The procedure is as follows;

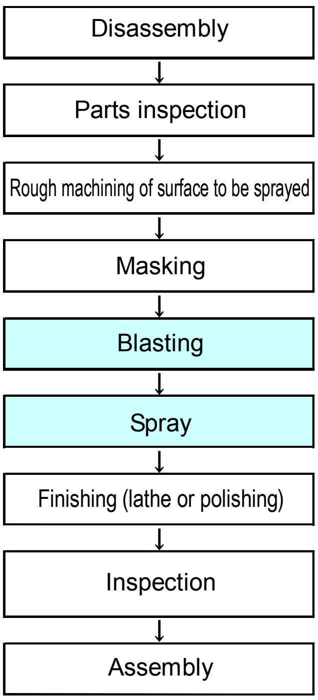


Fig. 4 Flow of parts recycle

(1) Disassemble and clean the components returned from the customers
(2) Check the damage of the parts
(3) Remove the worn portions and adjust the shape by rough machining
(4) Mask the areas which must not be sprayed.
(5) Roughen the surfaces to be sprayed by shot blasting
(6) Form a coating up to necessary thickness by spraying to restore the dimensions
(7) Finish by turning or polishing
(8) Inspect the coating and dimensions
(9) Assemble to each component

4. Characteristics of Sprayed coating

Fig. 5 is the picture of the cross section of a coating formed by the arc spray process. The sprayed coating consists of two kinds of coats. The coat marked Ni5Al in **Fig. 5** is called the Bond coat, and that marked 13Cr stainless steel is called the Top coat. Generally, the Bond coat is sprayed to increase the adhesion of the substrate material and sprayed coating and prevent peeling of the coating, and then the Top coat is sprayed to add the required properties for the part.

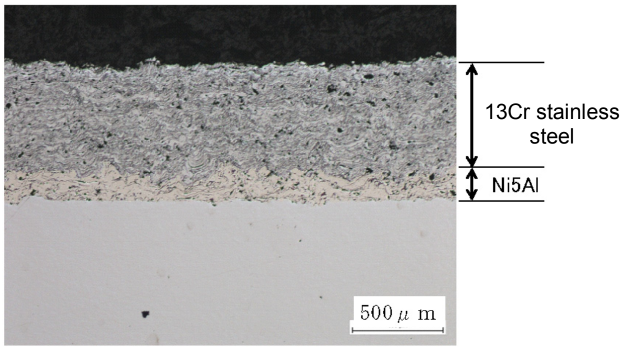


Fig. 5 Sectional structure of sprayed coating (Ni5Al+13Cr Stainless steel)

In this paper, the coating characteristics of Ni5Al (Bond coat) and 13Cr stainless steel (Top coat) are explained, which are used widely as spray material to restore the dimensions of precision machine parts.

4.1 Bond strength (Strength of adhesion) of Bond coat

When the substrate is a ferrous material, Ni5Al is applied as the Bond coat to prevent peeling. The parts to be recycled vary widely in material and property. We inspected if the bond strength of the coating varies with the substrate material.

It is known that the bond strength of the coating mainly depends on the anchor effect and the surface condition after shot blasting performed as the pretreatment of the spray has an impact on the bond strength. The surface condition is indicated by (1) roughness, (2) hardness, (3) existence of graphite (cast iron and steel), (4) cleanliness, etc. In this study, we compared and evaluated (1), (2), and (3) which seem to be affected by the type and properties of material.

Table 2 Evaluation levels of bond strength of coating

Material	Heat treatment (hardness)	Aim
SCM415H	GCQT (HRC62)	Effects of carburizing and quenching (hardness)
SCM440H	QT (HRC50)	Effects of quenching (hardness)
SCM440H	QT (HRC30)	Effects of quenching (hardness)
S45C	N/A	Inspection of common carbon steel
FC250	N/A	Effects of graphite flake
FCD450	N/A	Effects of nodular graphite

We evaluated the four types of steel and two types of cast iron as substrate materials having different hardness as shown in **Table 2**. **Fig. 6** shows the measuring method of the bond strength. We sprayed the Bond coat onto the end faces of the lower test pieces of the substrate materials in **Table 2** having different surface roughness, and then jointed them to the upper test pieces (S45C) with adhesive and performed a tensile test. The value of the breaking load / cross-sectional area was set as the bond strength.

Fig. 7 shows the test result. The horizontal axis indicates the surface roughness of the substrate material and the vertical axis indicates the bond strength. The breaking point was the interface of the Bond coat and substrate material in every case. If the surface roughness is high, the bond strength is stable and higher than 5 kgf/mm^2, regardless of the properties or hardness of the substrate material.

The adhesion strength of FC250 is a little lower than the other materials. It is supposed to be an impact of graphite. Extremely high surface roughness does not seem to increase the bond strength.

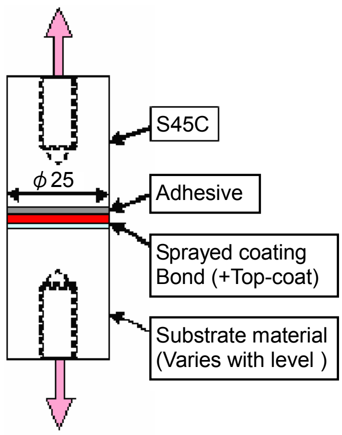


Fig. 6 Evaluation method of bond strength

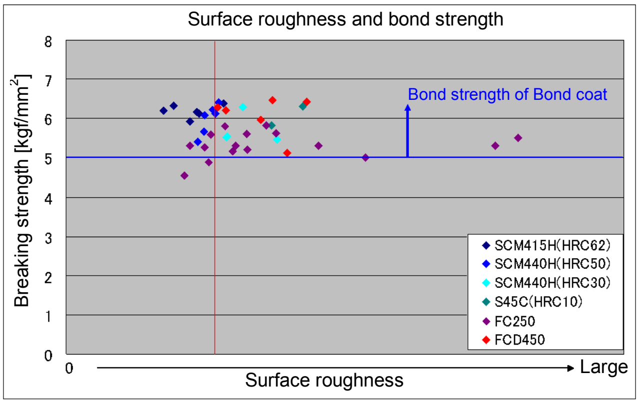


Fig. 7 Bond strength test result of Bond coat

4.2 Characteristics of top coat

The Top coat is sprayed to add the required properties for the part, and 13Cr stainless steel having higher wear resistance and corrosion resistance is used to restore the dimensions in many cases. The characteristics of the coating sprayed by using Ni5Al as the Bond coat and 13Cr stainless steel as the Top coat (the sectional structure is shown in **Fig. 5** above) are described below.

(1) Hardness

Fig. 8 shows the Micro-Vickers hardness of the Bond coat and Top coat. The average hardness of Ni5Al is MHv150 and that of 13Cr stainless steel is MHv470. The readers may think that the dispersion is wide. This dispersion is caused by the pores contained in the sprayed coating by 1 - 3%.

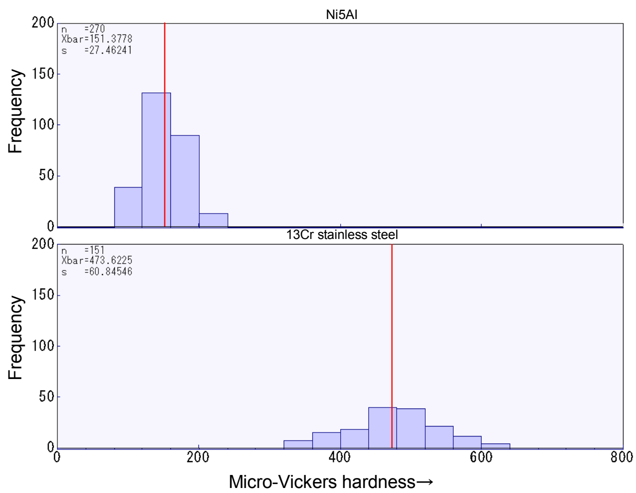


Fig. 8 Hardness of arc spray coating

(2) Breaking strength

Fig. 9 shows the result of the tensile test of the test pieces made by spraying Ni5Al over the substrate material and then spraying 13Cr stainless steel over it same as in the bond strength evaluation test of the Bond coat described in 4.1. Every test piece was broken within the top coat and the strength was about 3.5 kgf/mm^2.

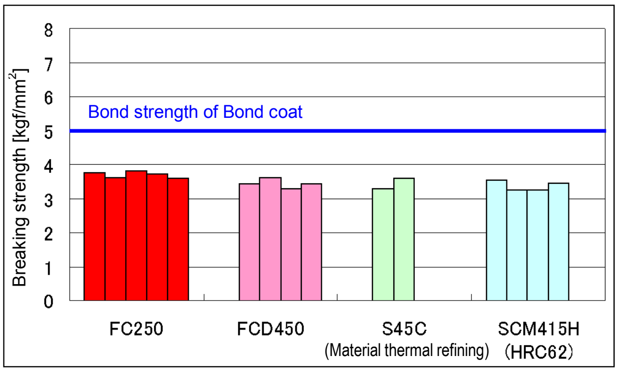


Fig. 9 Adhesion strength test result of bond coat and top coat

(3) Surface durability

Since the sprayed coating must not be fatigued or dented by the surface pressure of the mating part, we evaluated the surface durability. **Fig. 10** shows the test method. The pin 9 mm in diameter was pressed into the sprayed coating at the displacement speed of 1 mm/min and held at the test load for 10 seconds, and then the dent was measured. The same evaluate was applied to FC250 for the purpose of comparison.

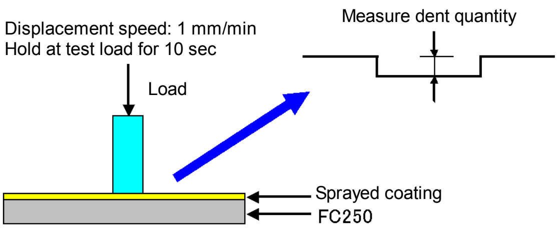


Fig. 10 Evaluation method of surface durability of arc spray coating

Fig. 11 shows the test result. The pressing surface pressure of the pin is plotted on the horizontal axis and the dent quantity is plotted on the vertical axis. This graph shows that the coating is not deformed until the surface pressure increases to a certain level and can be used similarly to FC250. The coating may be fatigued if the surface pressure increases more. Since the sprayed coating contains pores as described above, they seem to be flattened to causes deformation.

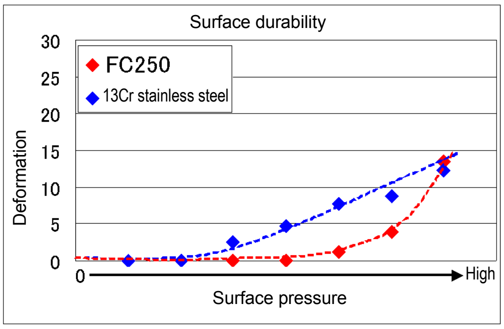


Fig. 11 Surface durability of arc spray coating

(4) Fretting wear resistance

If two solid surfaces in contact with each other are in small amplitude oscillatory motion in the tangential direction, they are worn. This form of wear is called fretting wear. We reproduced the fretting wear by applying 20-Hz oscillations 0.35 mm in amplitude with surface pressure of 0.05 kgf/mm^2 as shown in **Fig. 12**. We also applied this oscillation to FC250 for comparison.

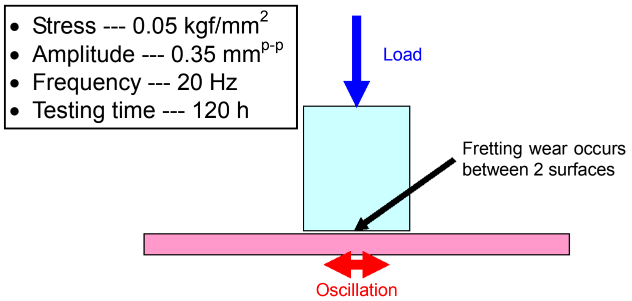


Fig. 12 Fretting wear test

Fig. 13 shows the test result. The fretting wear resistance of the sprayed 13Cr stainless steel coating is 10 times as high as that of FC250.

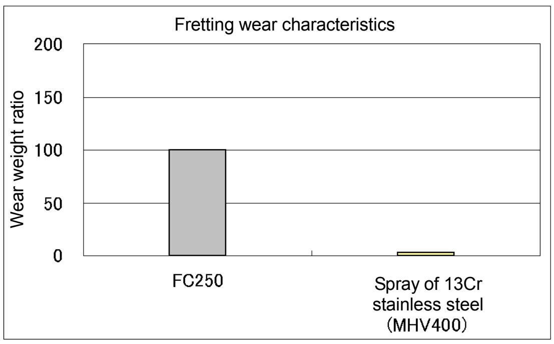


Fig. 13 Result of fretting wear test

Fig. 14 shows the concentration distribution of iron, chromium, and oxygen on the cross section of the sprayed 13Cr stainless steel coating measured by EPMA. There are chromium oxides having high hardness in the coating, which are produced during the process of arc generation through coating formation. These fine chromium oxides seem to be a factor of improvement of wear resistance.

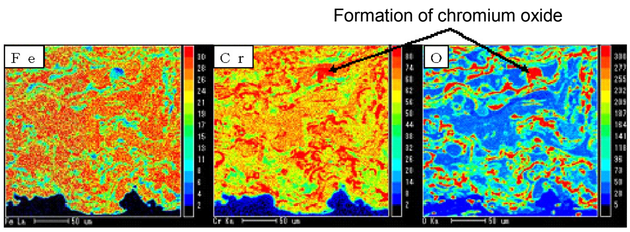


Fig. 14 EPMA result of sprayed 13Cr stainless steel coating

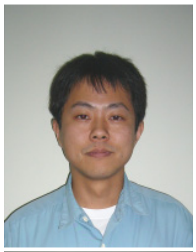
5. Conclusion

We studied the arc spray process as a technique of restoring the dimensions of worn parts and evaluated the characteristics of the 13Cr stainless steel coating and found the following.

- Hardness is about MHv470.
- Bond strength is 3.5 kgf/mm^2.
- Fatigue does not occur until surface pressure increases to a certain level.
- Fretting resistance is 10 times that of FC250.
- If the surface roughness after blasting is increased and Ni5Al is used as the bond coat, the adhesion strength of the film is stabilized, regardless of the type of the base metal.

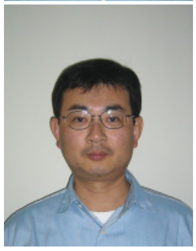
It is possible to build up the worn portions of the parts by the arc spray process if their strength and functions are satisfied with the above characteristics.

Introduction of the writers



Toshiyuki Iseki

Entered Komatsu in 2003.
Currently assigned to Remanufacturing & Solid Materials Team, Materials Group, Manufacturing Engineering Development Center, Production Division.



Masaharu Amano

Entered Komatsu in 1989.
Currently assigned to Remanufacturing & Solid Materials Team, Materials Group, Manufacturing Engineering Development Center, Production Division.

[A few words from writers]

In this report, we introduced the arc spray in the aspect of recycling and reusing damaged parts. However, how to reduce damages is also an important theme. We will observe various forms of damages of various parts and work on prevention and reduction of damages.