EFFECT OF SURFACE ROUGHNESS OF SUBSTRATE ON FATIGUE STRENGTH OF THERMALLY SPRAYED STEEL WITH SELF-FLUXING ALLOY

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ABSTRACT

In order to investigate the effects of the surface roughness of substrate on fatigue properties of a thermally sprayed specimen, three types of substrates with different surface roughness were prepared. After thermal spraying, two types of post heat treatments (fusing) were performed by an induction heating system for 200 seconds and a vacuum furnace for 0.5 hours. Then rotational bending fatigue tests were carried out. Two types of fatigue fracture mechanisms were observed; (a) A delamination between the coating layer and the substrate had occurred during the fatigue process and then the fatigue fractures started at the newly created surfaces of substrates at such boundary (*interface delamination mode*), (b) such a delamination had not occurred, but the fatigue fractures started at the surface of the coating (*coating fracture mode*). In the case of the interface delamination mode, substrate roughness strongly affected the fatigue strength of the sprayed specimen; the rougher the substrate surface, the higher the fatigue strength. This is because rougher substrate leads to higher adhesive strength between the coating and the substrate which is resulted from i) increase of the anchor strength and ii) increase of the physical adsorption strength. In the case of the coating fracture mode, however, the sprayed specimens showed very high fatigue strength irrespective of substrate roughness indicating that the surface roughness of the substrate had non effect on the fatigue strength of the sprayed specimen. On the other hand, the severe roughening of the substrate surface disturbed the improvement of fatigue strength. It is because excessive roughening of the substrate surface induces the micro void at interface between the coating and the substrate.

1 INTRODUCTION

A thermally sprayed coating is one of the popular surface treatment methods. With an increasing demand for the application of thermally sprayed coatings in several kinds of industries, it has become important to clarify the fatigue resistance of a steel with thermally sprayed coatings. In our previous research, it became clear that the adhesive strength between the coating and the substrate strongly affects the fatigue properties of thermally sprayed steel. In this study, we had an interest in the surface roughness of the substrate which can be considered to be one of controlling factors of the adhesive strength. The aim of the present study is to clarify the effects of the surface roughness of the substrate on the fatigue properties of steel thermally sprayed with a Ni-based self-fluxing alloy.

2 EXPERIMENTAL METHOD

A material (substrate) used in this study was a medium carbon steel with carbon content of 0.35%. After spraying, post heat treatment (fusing) was performed. In this study, two types of fusing were performed at 1010 deg C for 200 seconds by an induction heating system and for 0.5 hours by a vacuum furnace. Finally, six types of sprayed specimens were prepared. Fig.1 shows the flow chart of the preparation of the specimens. Fatigue tests were carried out by a rotational bending testing machine (3000rpm) at room temperature.

3 RESULTS AND DISCUSSION

Fig.3 shows the results of measurements of the surface roughness. We could prepare three types of substrate adequate for the present study. To investigate the effect of two types of fusing conditions on properties of coatings, we measured the hardness, Young’s moduli, and the porosity of the coatings. As a result, there were no noticeable differences in the coating characteristics among the six types of sprayed specimens with different holding times and with different substrate roughness. Fig.4 shows the results of fatigue tests of the specimens which were performed fusing by an induction heating system for 200 seconds, where the S-N diagram is given as a figure showing the number of cycles to failure versus the nominal stress amplitude at specimen surfaces. It is observed that all sprayed specimens indicate high fatigue strengths compared with that of substrate itself. In order to examine the fatigue fracture mode, all fracture surfaces were investigated by using a Scanning Electron Microscope (SEM). A delamination between the coating layer and the substrate had occurred during the fatigue process and the fatigue fractures started at the newly created surfaces of substrates at such boundary. We denominate this fracture mode an *interface delamination mode*. Fig.5 shows the relationship between the fatigue life and local stress amplitude at the fatigue fracture origin calculated by FEM analysis considering the differences in the Young's moduli between coating (E_c=270GPa) and substrate (E_s=206GPa). It is observed that all S-N curves lie at nearly the same stress level. However, albeit only slightly, it is observed that the surface roughness of substrate affects the fatigue properties; the rougher the substrate, the higher the fatigue strength. This is because rougher substrate leads to higher adhesive strength between the coatings and the substrate. In general, the adhesive strength between the coating and the substrate increases with i) an increase of anchor strength involved in the surface roughness, ii) increase of metallurgy allegation involved in the heat treatment process, and iii) increase of physical adsorption strength involved in increase of surface area due to roughening. In the case of present study, it is easy to assume that A series specimens had the highest adhesive strength for the anchor effects. As for an adhesive strength caused by metallurgy allegation, there was no significant difference between these specimens because the fusing condition was the same. Adhesive strength resulted from physical adsorption is affected by the increase of surface area due to roughening. So, increase ratio of the surface area after roughening was measured. As the result, it became clear that A series had the largest increase of the ratio of the surface area. Indicating that, adhesive strength between the coating and the substrate becomes high in order of series A, B and C.

Fig.6 shows the results of fatigue tests of the specimens for which were fusing was performed by vacuum furnace for 0.5 hours, where the S-N diagram is given as a figure showing the number of cycles to failure versus the nominal stress amplitude at specimen surfaces. It is observed that both of B+spray(V) series and C+spray(V) series specimens indicate very high fatigue strength. However, A+spray(V) series exhibited the same level of fatigue strength as that of the sprayed specimens fused by an induction heating system in Fig.4. In order to examine the cause, fracture surfaces were investigated by using the SEM. The fatigue fractures of B+spray(V) series and C+spray(V) series specimens started at the surface of the coating. We denominate this fracture mode a *coating fracture mode*. In the case of this fracture mode, the surface roughness of the substrate had non effect on the fatigue strength of the sprayed specimen. On the other hand, in the A+spray(V) series specimens, delamination between the coating and the substrate occurred and then followed by fatigue fracture. In order to examine the cause, we observed the condition of the microstructures near the interface in detail. As a result, a lot of micro voids were observed at such interface only in the A+spray(V) series specimens. This is because the surface of the substrate in series A was so severely roughened that a lot of micro voids remained after fusing at the location of the surface of substrate in the microstructure. It can be said that too much roughening of substrate surface disturb the improvement of the fatigue properties.

4 CONCLUSIONS

In order to investigate the effects of the surface roughness of substrate on fatigue properties of a thermally sprayed specimen, three types of sprayed specimens with different surface roughness of the substrate were prepared. The rotational bending fatigue tests were carried out. The results are summarized as follows:

(1) In the sprayed specimens which were fused by the induction heating systems for shorter holding time, the delamination occurred between the coating and the substrate during the fatigue process and fatigue fractures started at the newly created surface of the substrate at such boundary (*interface delamination mode*). In the case of this mode, the surface roughness of the substrate affected the fatigue properties; the rougher the substrate, the higher the fatigue strength. This is because rougher substrate leads to higher adhesive strength between the coatings and the substrate.

(2) The long time fusing specimens in which fatigue fracture starts at the surface of the coating (*coating fracture mode*) indicate higher fatigue strength than that of short time fusing specimens. And in the case of this fracture mode, the surface roughness of the substrate had non effect on the fatigue strength of the sprayed specimen.

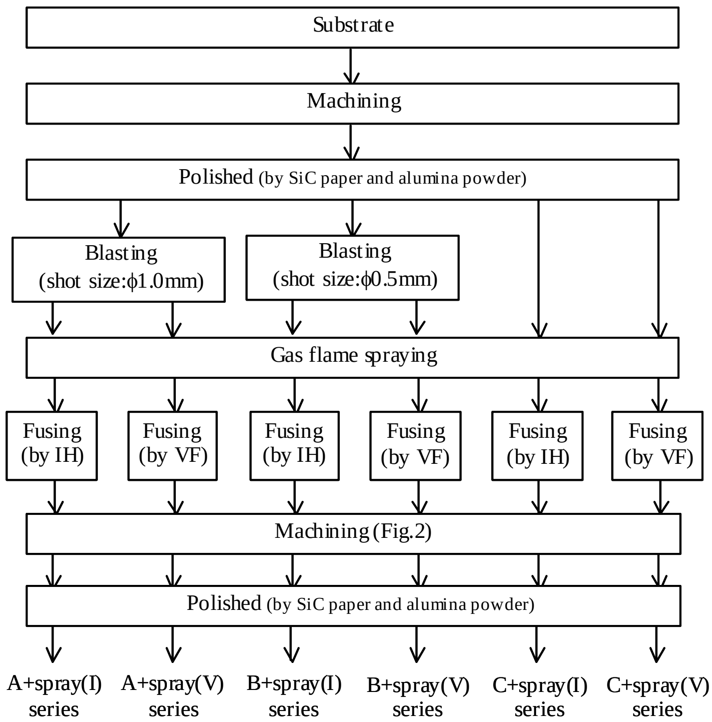

Fig.1 Flow chart

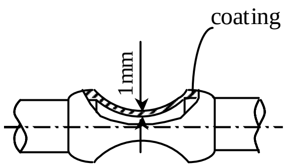

Fig.2 Schematic illustration of sprayed coating

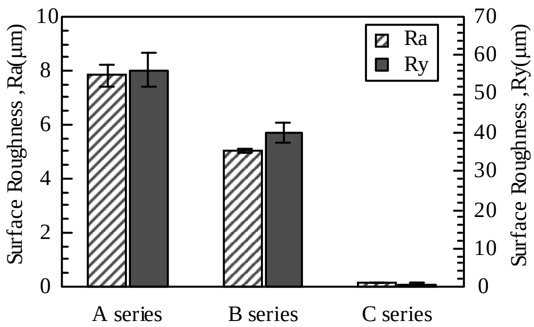

Fig.3 Result of surface roughness

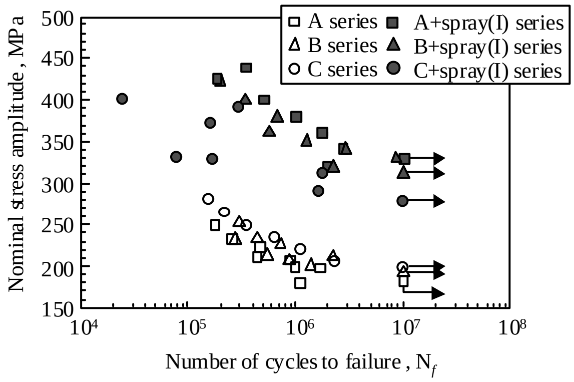

Fig.4 Result of fatigue tests

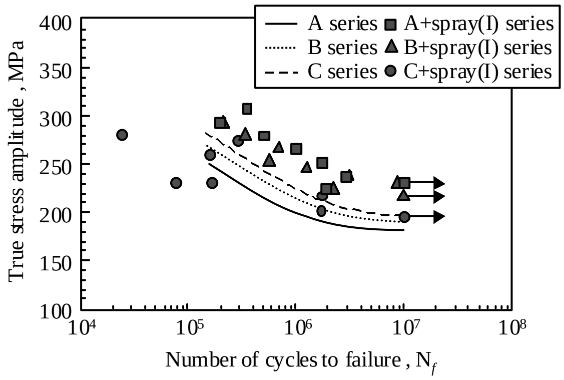

Fig.5 Result of fatigue tests

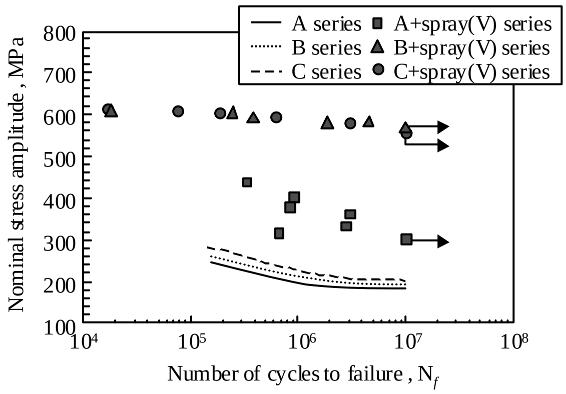

Fig.6 Result of fatigue tests