INFLUENCE OF SHOT PEENING ON FATIGUE STRENGTH OF FRICTION WELDED JOINT.

H.Suzuki 1 M.Hasegawa 2

1 SINTOKOGIO, LTD., Nagoya, Japan
2 Chubu University, Aichi, Japan

ABSTRACT

Effects of base metal hardness on improvement of fatigue strength by shot peening treatment are investigated using various carbon steels for machine construction. Furthermore, an effect of shot peening treatment on improvement of fatigue strength of friction pressure welding is investigated.
The results are summarized as follows.
1) Fatigue strength of a friction welded joint becomes higher than the base metal although the flash does not be removed if shot peening treatment is applied.
2) The fatigue strength increases in proportion to the raise in hardness near the surface in the both cases of base material and the one with shot peening treatment.

Key words
shot peening, friction pressure welding, hardness, fatigue strength, carbon steel

INTRODUCTION

Friction pressure welding is a technology to bond material by rubbing at high speed, softening by the friction heat, and simultaneously applying pressure to bond the material. The friction pressure welding (to be shortened as FPW) features such advantages as “Bonding of dissimilar metals is possible”, “Strength of joints and dimensional accuracy are high”, “High economical efficiency”, etc. This welding process is attracting worldwide attention for its friendliness to environment. It is anticipated that the bonding of dissimilar metals, in particular, will expand its application fields quickly. Most industries are paying notice to its advantage of reducing the weight of products and parts while making them highly sophisticated at lower cost.

On the other hand, in case of the majority of conventional FPW joints, the flashes formed at the friction welded parts were removed from view and prevent decrease of fatigue strength due to stress concentration. In future, it is anticipated that the application of FPW for the bonding of parts where deburring is difficult will increase, and the joints will be used with burrs as they are. With regard to the burrs, from the view point of fatigue strength, the author and his team previously clarified that a slight residue of burrs can decrease the fatigue strength significantly[1)]. Therefore, in case of applying FPW to the place where deburring is difficult, such countermeasures as thickening the diameter of material and the like will become essential, and the effect to lighten the weight will be reduced.

In this research, flat plates of various carbon steel of machine structural grade were used as the base material. Shot peening was conducted under the same conditions to investigate systematically to what extent the hardness of base material can influence the

improvement of fatigue strength by shot peening. In addition, as stated above, in case of carbon steel lower than S35C, any adjustment in thermodynamic cycle and upset pressure could not stop the decrease of fatigue strength where the removal of burrs (deflashing) was essential. Accordingly, the study was carried out to investigate the effect of shot peening on fatigue strength of low carbon steel joints with burrs, friction pressure welded under typical FPW conditions.
All the results are hereby reported.

Method of Experiments

In this study, 4 different kinds of carbon steel for machine structural grade such as S25C,S35C, S45C and S55C are used. The chemical and physical compositions of the materials are shown in Table 1. Test pieces of FPW joint and flat test pieces for comparison were used for rotating bending test, and the effects of shot peening were evaluated. The rotating bending test was conducted at room temperature.

Table1 Chemical compositions of Carbon steel.

Materials	Diameter, mm	Chemical composition , mass%							Vickers hardness, HV0.01
		C	Si	Mn	P	S	Ni	Cr	
S25C	16	0.23	0.17	0.40	0.02	0.019	0.04	0.14	159
S35C	16	0.35	0.18	0.75	0.02	0.015	0.04	0.16	180
S45C	16	0.45	0.17	0.74	0.01	0.014	0.04	0.17	225
S55C	16	0.54	0.16	0.86	0.01	0.009	0.04	0.18	237

Flat fatigue test pieces with the shape and dimensions shown in Fig.1(a) were prepared by machining. For preparing FPW test pieces, the flat fatigue test piece was divided into 2 from the center as shown in Fig. 1(b), and joined together by FPW and used as the burrs are left attached. [2,3].

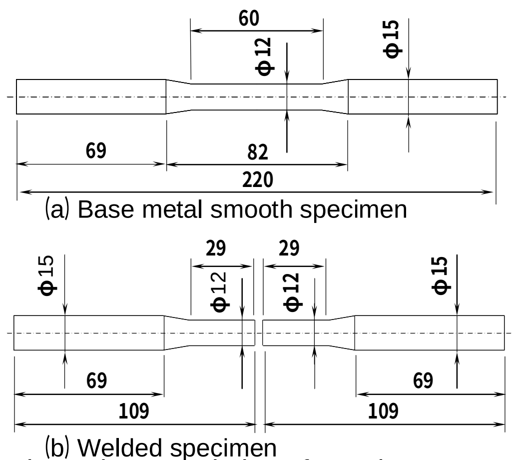

Fig.1 Shape and size of specimen,mm.

FPW conditions were set as: RPM of test piece 3600m in^{-1}, Friction Pressure P1 = 51MPa, Upset Pressure P2 = 94MPa. These are the typical FPW conditions normally used. In the study conducted previously by one of the authors for using friction welded joints with burr on, it was proven that the fatigue break of all types of carbon steel, the same as the test pieces used in this experiments took place at the toe part of burr, and that the FPW conditions applied here resulted the fatigue limit of friction welded joints substantially lower than that of the base plate material[2,3].2-pass of shot peening treatment were conducted by using the shot having average particle size of 150 μm, hardness Hv1400 and specific gravity 14, under such conditions as blasting pressure 0.2MPa, blasting angle 45°and processing time 12s.Fatigue test with repeating speed of 3500min^{-1}was conducted under room temperature. In this experiment, the fatigue limit was set as 2 x 10^{6} cycles, and arrow marks were put to the test pieces that didn't break by this numbers of repetition. Besides the fatigue test, measuring of the hardness and the distribution of residual stress was conducted by using micro-hardness tester.

Result of Experiments and Related Study

Fig. 2 shows the fatigue test results using the test pieces of flat base material. It was recognized that the shot peening treatment on any test piece of flat base material achieved improvement of fatigue limit. The improvement effect varies depending on the hardness of base material. It is proven that the material with higher carbon content and higher hardness achieved greater improvement effect. For example, S55C has the highest carbon content and the highest hardness. The fatigue limit of flat base material of S55C without peening treatment was 318MPa. After shot peening treatment, the fatigue limit was 353MPa, improved by about 35MPa. In contrast to this, the fatigue limit of S25C, the lowest C content and softest material, was as low as 278MPa after peening. The improvement was only 18MPa, about 50% of the improvement effect of fatigue limit achieved by S55C.

Fig. 3 shows the result of measurement of residual stress distribution to the depth direction of the test pieces of base material and the peening treated base material of S25C and S55C. This figure indicates that there is the peak value of residual compressive stress of about -464~-490MPa at the proximity of about 10μm from the surface irrespective of carbon content. It is also observed that the width of residual compressive stress of S55C is slightly wider than that of S25C.

Fig. 4 shows the result of measurement of hardness distribution to the depth direction from the surface of the test pieces of untreated base material and peening treated base material of S55C, the highest C content, and S25C, the lowest C content. In either case, the uniform increase of hardness to the proximity of about 30μm from the surface is recognized regardless of carbon content of the test piece.The increasing hardness of S55C with the higher carbon content is significant. Compared to the hardness of untreated material of about Hv237, the hardness of peening treated material was about Hv301. The increase of about Hv64 was recognized. On the other hand, the hardness of untreated S25C was Hv159 whereas the peening processed S25C was

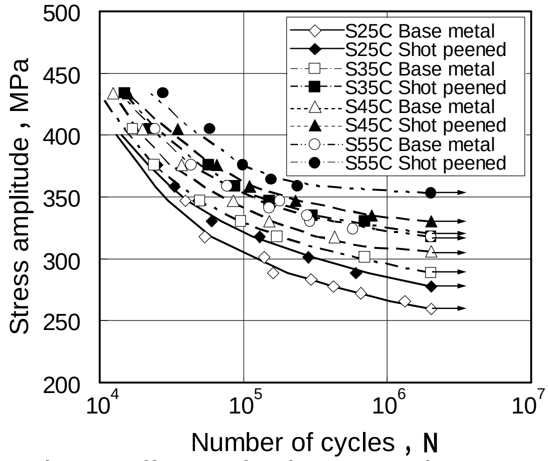

Fig.2 Effect of shot peening on fatigue strength.

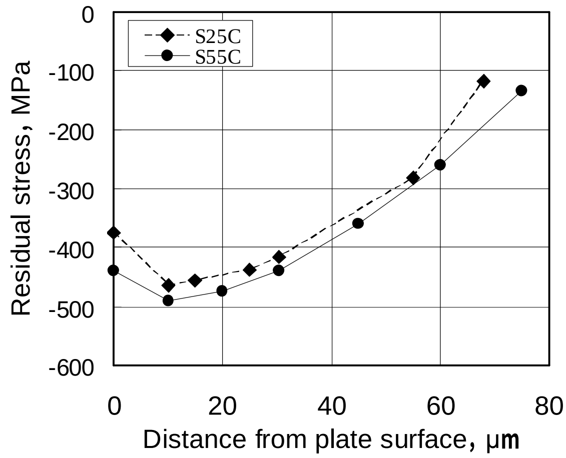

Fig.3 Effect of shot peening on residual stress distribution.

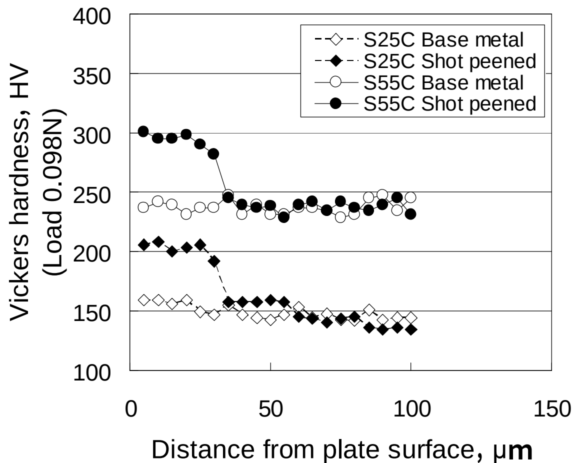

Fig.4 Effect of shot peening on hardness distribution.

Hv206 showing the lower increase of Hv47. This result showed that the hardness after shot peening improved, so that a base material is hard.

Fig. 5 indicates the relation between hardness and fatigue limit at the depth of 10μm from the surface. Irrespective of carbon content, there is correlation between surface hardness and fatigue strength, and it was clarified that the hardness of surface vicinity is one of the key factors for determining the fatigue strength.As the main factors for giving great influence on fatigue strength, it is possible to point out stress concentration, hardness and residual stress.In case the micro-fine shot is used, as reported previously, there is almost no variation in stress concentration[2)] and, as shown in Fig. 3, no obvious difference was recognized in residual stress value. From these results, in case of carbon steel materials used in this test, it is considered that the fatigue strength can be estimated by measuring surface hardness.

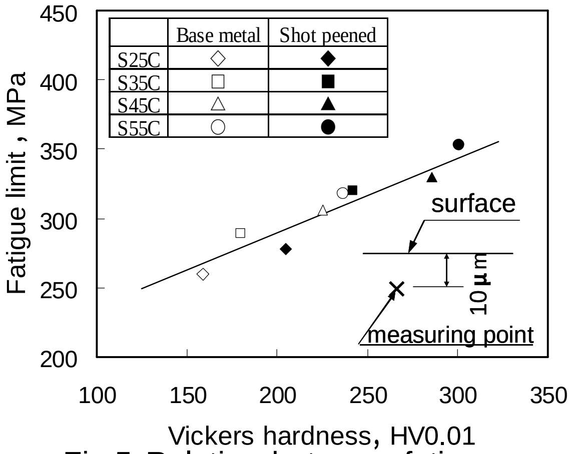

Fig.5 Relation between fatigue limit and Vickers hardness.

Fig. 6 shows the results of fatigue test using S25C and S55C test pieces of FPW joints with burrs. Furthermore, Fig. 7 is the appearance photograph showing FPW joint without peening treatment and that of peening treated after fatigue break. According to Fig. 7, the fatigue limit of S25C is 226MPa while that of S55C is 272MPa.Comparing these values with the fatigue limits of base plate materials, it is possible to find the decrease of about 29MPa and about 43MPa respectively. In both cases, the fatigue break took place at the toe part of the burr as shown in Fig. 8. As reported previously[2)], this is the result of stress concentration due to upset pressure P_2 on the toe part of burr. However, if these test pieces undergo shot peening treatment, no fatigue destruction at the burr of the toe part is observed, but the destruction takes place at the parallel part of the flat base material. As a matter of course, the fatigue limits of the above cases are identical with the fatigue limits of peening treated flat base materials (273MPa and 353MPa) which are much higher than those of the untreated flat base material. Accordingly, in case the removal of burr is impossible due to the restriction by geometrical shape, or due to excessively high hardness imparted by FPW, or in case the burrs are permitted in appearance, shot peening treatment will help. It is possible to expect the substantial expansion of application range of FPW method, and the great reduction of the cost required for deburring.

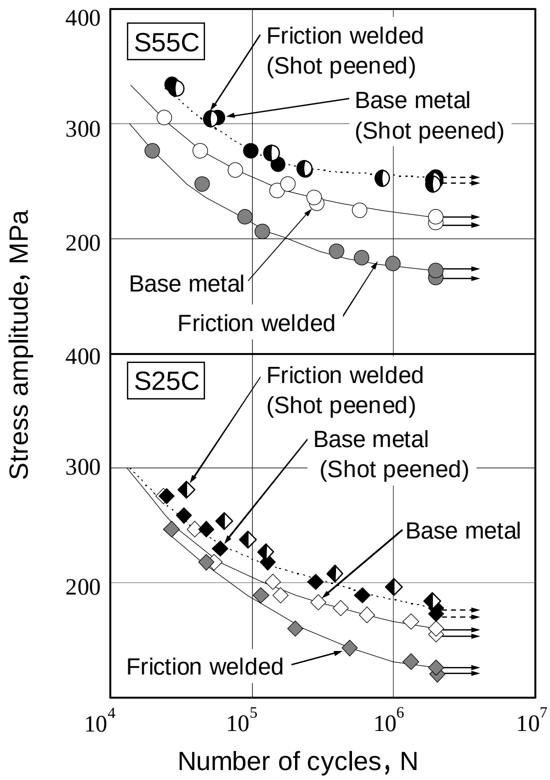

Fig.6 Effect of shot peening on fatigue strength.

Fig. 8 describes the distribution of hardness in S55C FPW joints. The measurement was conducted at the depth of 10μm from the surface, parallel to the parallel part up to the friction welded surface. In case of shot peened test piece, the measurement in the range from welded surface to the toe of burr was not conducted. Instead, the hardness of burr part at 0.7mm from the surface of parallel part marked as A in the figure was measured in addition. As the measuring result of hardness distribution shown in Fig. 5 indicates clearly, the influence of shot peening on hardness reaches to the depth of more or less 30μm, and therefore, the measuring of this range can never grasp the variation of hardness precisely. In the measuring result of friction welded joint, the hardness of welded surface is about Hv286, the highest among others. However, it is getting lower towards to the base plate, and with such trend, the hardness at the position of about 7mm from the welded surface fell and equals the hardness of the flat base material. In addition, the hardness at burr toe part after shot peening treatment was recognized as about Hv343, the increase of about Hv92 against about Hv251 of the base material without shot peening. It is also confirmed that the hardness of measuring point A is about Hv343, equal to the hardness measured at burr toe part.

Fig. 9 shows the measuring result of residual stress at the toe part of FPW joints. In both test pieces of S25C and S55C, even in as-welded state, the residual compressive stress of about -300MPa or above was confirmed. The amount of increase of residual compressive stress is less than that of the parallel part. At the same time, it was recognized that the value of residual compressive ratio and the magnitude of increase was greater in S55C compared to S25C, but the difference is small. With regard to the distribution of residual compressive stress to the depth direction, it was impossible to obtain the stable values probably because the distribution near the burr toe part was quite complicated. These facts indicate that the shot peening cannot

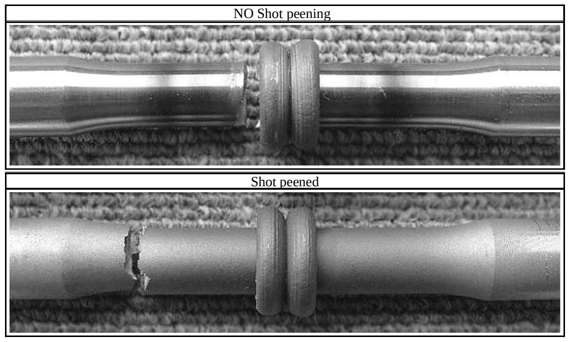

Fig.7 Comparison of fractured specimens under the conditions with and without peening.

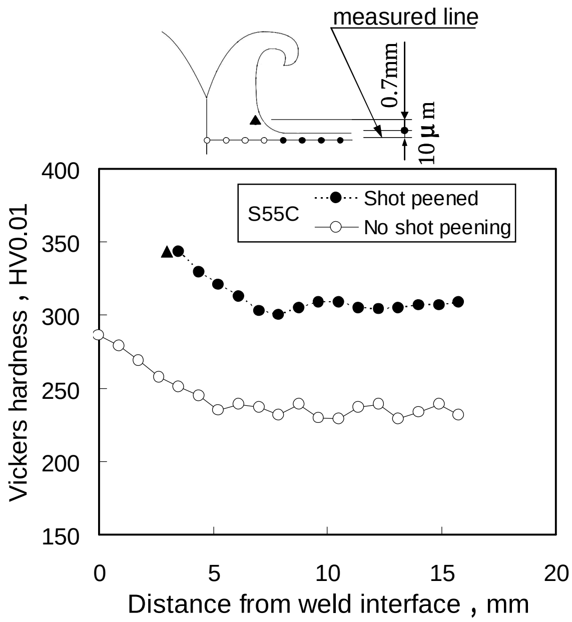

Fig.8 Effect of shot peening on hardness distribution.

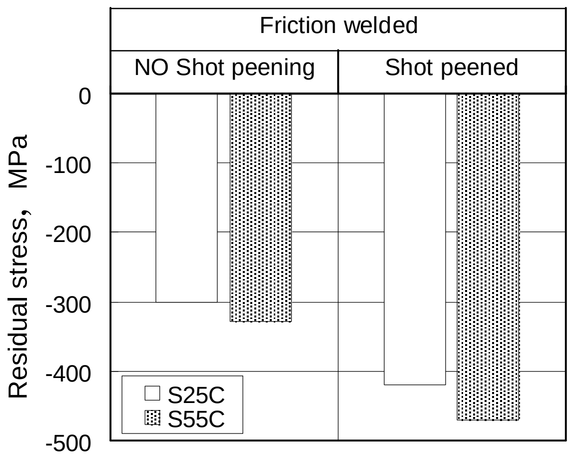

Fig.9 Effect of shot peening on residual stress distribution.

do much for the improvement of fatigue strength by imparting residual compressive stress.

Accordingly, the reason why the fatigue break did not take place at the burr toe part even though the stress concentration was focused to this part, was that the hardness of burr toe part increased significantly with the heat effect of friction welding much more than the hardness of base plate material. Also, the fatigue limit by stress concentration superseded the fatigue limit of base plate material.

Conclusion

The influence of hardness of base plate material on the effect of fatigue strength improvement by shot peening as well as the influence of shot peening treatment on the fatigue strength of FPW joints with burrs were investigated by using various carbon steel of machine structural grade as base test materials. The results obtained are as follows.

1) The effect of shot peening on the improvement of fatigue strength is apparent and more obviously in the harder base material.
2) By conducting shot peening treatment on FPW joints, it is possible to obtain the FPW joints having the fatigue strength higher than that of the base material without removing burrs.
3) In the base materials with or without shot peening treatment, correlation is recognized between fatigue strength and the hardness near the surface irrespective of carbon content.

References

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