Application of ultrasonic peening to improving fatigue properties of welded joints

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ABSTRACT

Fatigue strength of welded joints in welded structures are much lower than that of base metals. Many experiments show that the fatigue crack normally initiates at welded toe, so that the fatigue strength can be increased dramatically by peening weld toe.[1,2,3]

Ultrasonic peening made by Tianjin University in China under the financial support of Natural Science Foundation of China is one of the most useful methods to improve fatigue behavior of weld toe due to improving toe geometry, removing defects and modifying the residual stresses distribution in this region.

For evaluating the ultrasonic peening performance carried out by our equipment, the fatigue tests were performed on butt and cruciform joints of Q235B steel both in the as-welded and peened condition. Test results are as follows:

1.Both butt and cruciform peened joints show a significant increase in fatigue life under different stress levels (high cycle fatigue). The results show that the fatigue life of the peened weld toe was 20~30 times as long as the as-welded joints, and in many cases the fatigue cracking initiation was transferred to the base metal instead of the weld toe.

2.The increase in fatigue strength (at 2×10^6 cycles)of the peened Q235B butt welded joints compared to the as-welded joints was 57%,and for the cruciform joints, the increase was 64~71%. The fatigue strength of both the butt and cruciform welded joints were no lower than that of the base metal. In such cases, weld joints is not the degense location any longer.

1. INTRODUCTION

Fatigue is one of the main forms of the failures of the welded structure. Many experiments show that the fatigue crack mainly initiates at the weld toe, so that the fatigue strength can be increased by treatment the welded toe.[1.2]

Ultrasonic peening made by Tianjin University in China under financial support of Natural Science Foundation of China is one of the most useful methods to improve fatigue life due to improving toe geometry, removing defects and introducing benefit compressive residual stress, as well as 1) It can be used not only for plate butt joints, but also for the tube joints, to which it is difficult by using other methods, such as TIG dressing. 2) It can be applied not only to the process of structure manufacturing in the working shop, but also to the field welding condition such as to bridges, oil platforms, ships and so on. 3) High treatment velocity (at the velocity of half meter per minute). 4) Other advantages: it don't produce noise; the whole device is not heavy. (the peening unit weight is only several kilograms.)

Fig.1 is the picture of the ultrasonic peening device. One of the most important part in peening device is energy transform part, which based on piezoelectric ceramic transducer, is convenient to use for its small size, light weight, lower power to supply and easy to apply. The equipment is matched with the special ultrasonic power generator which used IGBT as the higher power component, matched with delicate frequency tracing system and the constant vibrating velocity control system, controls the quality of the ultrasonic peening results. The peening unit, named ultrasonic peening gun, consists of the sound system, shell and holder, and was designed to give high treatment velocity (at the velocity of half meter per minute) and strong peening force.

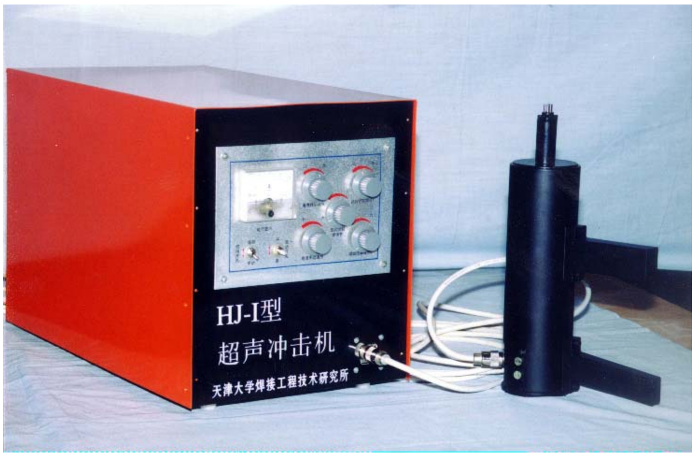


Fig.1.Ultrasonic peening device

2. MATERIAL, SPECIMENS AND TESTING CONDITION

Table 1.Mechanical properties of Q235B steel

material	σ_s /MPa	σ_b /MPa	δ
Q235B	267.4	435.5	26%

The material used in this research program is Q235B steel. Table 1 gives the mechanical properties of this steel. Both as-welded and peening conditions of the cruciform (under tensile) and the butt (under four-point bending) joints were considered in this study. The welding parameters are given in table 2.

2.1.Preparation of butt Welded Joints

On the surfaces of each piece of the specimen, a X groove was cutting and a thickness equity to 1mm was left in the middle of the specimen in order to prevent or reduce distortion. The welds were produced in two passes by manual arc welding with J422 electrode.

Table 2. Welding process parameters

Joints	（1 pass）welding current（A）	（2 pass）welding current（A）	Welding Voltage（V）
Butt joints	110	120	24~30
Cruciform joints	130	150	25~30

2.2.Preparation of Cruciform welded joint:

A X groove with 60° angle was cutting for the load-carrying piece of the specimen. The welds were produced in two passes by same manual arc welding with J422 electrode. In order to prevent or reduce distortion, spot-fixing weld was accepted and opposite distortion was taken before welding.

2.3.Fatigue Tests:

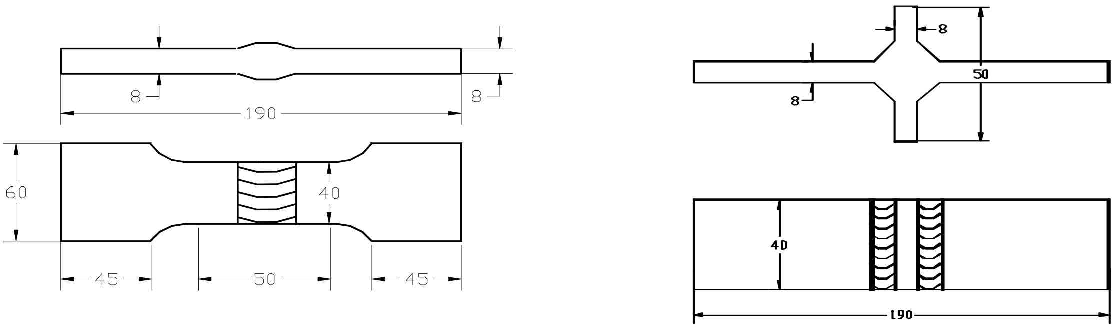


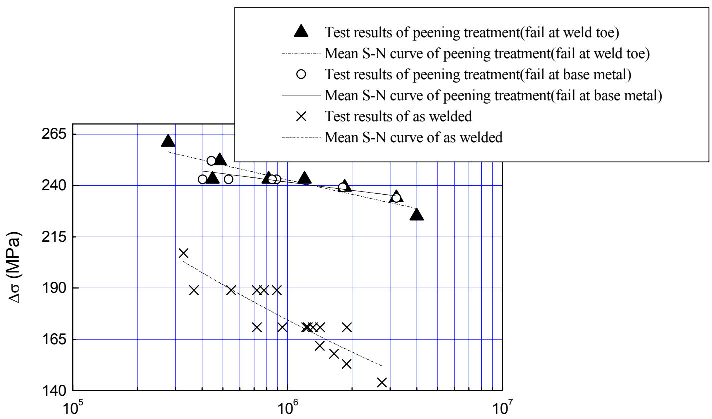
Fig.2.Shapes and dimensions of speci

The fatigue tests were performed on a high-frequency fatigue testing machine with a capacity of 100KN. For the butt joints subjected to tensile loads, a stress ratio R=0.1 was selected. For the cruciform joints subjected to four point bending, the stress ratio R=0.25 and R= - 0.5 were selected.

2.4.Ultrasonic Peening Operation

The peening gun was held approximately normal to the weld face and inclined at 45° to the base metal surface. The gun was move along the weld at an approximate speed of 0.5m/min and two times peening were used to obtain smooth weld toe geometry. The current of the device used is 0.5 ampere.

3.EXPERIMENTAL RESULTS AND DISCUSSIONS



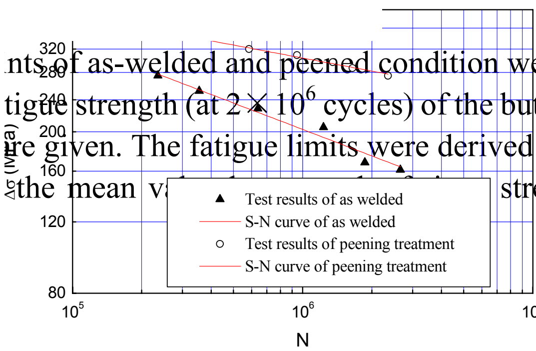
F utt joints (R=0.1)

nts of as-welded and peened condition were

p tigue strength (at 2×10^6 cycles) of the butt and

c re given. The fatigue limits were derived from

tl the mean v strength



ig.5.S-N curves of cruciform joints (R= - 0.5)

corresponding to the specimen, whose life is just higher than 2×10^6 and the fatigue strength corresponding to
the specimen ,whose life is just lower than 2×10^6.

The results from S-N curves are as follows:

Compared with welded joints, the peened joints show significant increase in the fatigue life under different stress levels and the fatigue strength at a cycles 2×10^6.

On the butt peened joints, fatigue crack initiated at the weld toe under cycles much more than that on the as welded joints for some specimens, however for more specimens, fatigue crack initiation occurred in the base metal. The S-N curves of both crack initiation conditions are similar in the slope and fatigue stress levels, so that the fatigue strength of the peened joints can be considered as same as the base metal. Compared to the as-welded joints, the increase in fatigue strength (at 2×10^6 cycles) of the peened Q235B butt joints was 57%. For the cruciform peened joints, most cracks occurred in the base metal. The increase in fatigue strength of the peened cruciform joints tested with R=0.25 was 64%. For the specimen tested with R= -0.5, the increase was 71%.

Table 3. The fatigue limit of welded joints and with peening treatment joints

Type	Fatigue strengths (Δσ/Mpa)		
	As welded	Treatment	Improving degree/%
Butt joints	148.5	234	57
Cruciform joints （R=0.25）	142.5	234	64
Cruciform joints （R=-0.5）	165	282	71

Table 4 gives the fatigue life (under the same stress level) of the two series joints. According to the S-N curves (see from fig.3, 4, 5), the fatigue life of welded joints corresponding to the stress which comes from the peened joints corresponding to 2×10^7 cycles can be obtained. The results shows in Table 4.

Table 4 . The fatigue life of welded joints and with peening treatment joints

Joints	Condition	Stress	life
Butt joints （R=0.1）	As welded Treatment	228 228	1.65×10^5 1.0×10^7
Cruciform joints (R=0.25）	As welded Treatment	211 211	2.4×10^5 1.0×10^7
Cruciform joints (R= - 0.5）	As welded Treatment	235 235	5.12×10^5 1.0×10^7

Analysis of the results shows that the fatigue life of the peened joints was 40~60 times as long as the as-welded joints. Provided that the deviation of the test results were taking into consideration, the improvement was 20~30 times.

Test results reveal that the ultrasonic peening was an effective technique for improving the fatigue properties of the welded joints. The fatigue strength of the peened joints was nearly equal to the base metal. In such cases, welded joints is not the degense location any longer.

4.CONCLUSIONS

1) Both the butt and cruciform peened Q235B joints show a significant increase in fatigue life under different stress levels (high cycle fatigue), and also increase in fatigue strength under the same cycles. The difference in stress level was increasing with the increase of cycles.

2) The relative improvement in fatigue limit (at 2×10^6 cycles) caused by ultrasonic peening of the butt and cruciform joints were respectively 57%and 64%~71% compared with the as-welded condition.

3) The fatigue strengths of both the butt and cruciform welded joints were no lower than that of the base metal, when ultrasonic peening of the joints were carried out. Compares with the peened butt welded joint, the fatigue of cruciform welded joints after peened are increased more significantly.

4) The fatigue life of peened joints at least was 20~30 times as long as the as-welded joints.

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