J MATER RES TECHNOL. 2020;9(4):7100–7103

Available online at www.sciencedirect.com

jmr&t
Journal of Materials Research and Technology
www.jmrt.com.br

Short Communication

Study on the plastic deformation zone of Q235 steel *via* hammering tight seam

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ARTICLE INFO

Article history:
Received 4 March 2020
Accepted 8 April 2020
Available online 8 June 2020

Keywords:
Hammering tight seam
Plastic deformation zone
Plastic raised area
Fatigue
Metals and alloys

ABSTRACT

The formation of pre-stressing layer with certain depth on the surface *via* hammering can effectively prolong the fatigue life of parts. It is necessary but difficult to accurately analyze the symmetry and synchronism of plastic deformation zone formed by hammering. In this work, we, herein, create an experimental method that tights the Q235 steel rods together *via* external force and study the plastic deformation zone near tight seam. Through morphology analysis, it is found that the cross profile of plastic deformation zone near tight seam is circular and radially symmetrical, indicating that the sharp of internal plastic deformation zone is spherical. Additionally, the result of dynamic strain experiment confirms that the result obtained by hammering the tight seam is reliable.

1. Introduction

The surface peening is considered as an effective method to enhance the fatigue strength and prolong the fatigue life of component. The formation of plastic deformation zone is critical to the improvement in surface properties of component. Nowadays, various methods including stress relaxation, magnetic method, X-ray diffraction, ultrasound and shock indentation, have been developed to investigate the formation of plastic deformation zone [1–5]. However, all of these methods have some drawbacks. For instance, the most common method is shock indentation. Chen et al. have done lots of researches about plastic deformation zone *via* shock indentation method [6–11]. For the shock indentation method, the plastic zone study is based on the finite element analysis, in which the preset of process model and boundary condition seriously influence the results, leading to the uncertainty. Previously, we created a tight hammering method to investigate the curved-surface plastic deformation zone, and successfully analyzed the effects of surface morphology and other factors [12]. In this work, we present this novel method to analyze the plane-surface plastic zone, and overcome the uncertainty of previous methods for plastic zone analysis.

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https://doi.org/10.1016/j.jmrt.2020.04.030

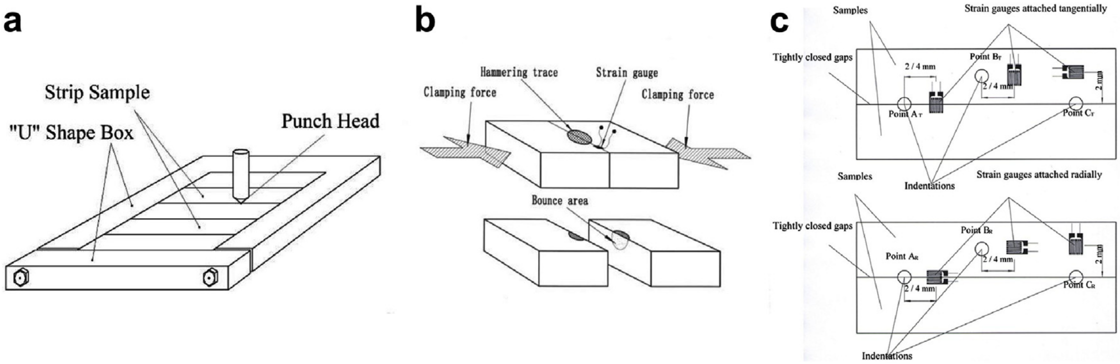

Fig. 1 – (a) Schematic illustration of hammer test. (b) The assembly of two steel rods. (c) The locations of strain gauges.

2. Experimental

In the hammering process, the plastic zone formed by the single-point impact on the surface of an isotropic material (including quasi-isotropic materials) must be symmetrical. The punch head impacts the surface along the axial line, and thus an axisymmetric plastic zone is formed inside the material (Fig. 1a). When hammering the tight seam, a compression force perpendicular to the surface is generated on both side of seams, but the apparent shear stress would not be produced. Thus, two pieces of identical materials can be regarded as joined during hammering if they are tightly connected to form the ideal bonding strength. In other words, the result from the impact test conducted at the bonding surface would be the same with that at the continuous surface. Based on these findings, we design the tight hammering method, which is presented as follow.

The dimensions of Q235 bars are 170*20*30 mm^3. The bar surfaces to be hammered and be pressed are ground until the surface roughness is 0.4 μm. The hammer test device consists of a 2D manual platform (X- and Y-direction movement precision = 0.05 mm), holders, straight-line guide rails, sliders and SΦ11 punch head. The weight of the slider with punch head is 4.7 kg. The hammer strokes are 25, 50, 75, 100, 125 and 150 mm, respectively.

Two steel rods are tightened together as one sample (Fig. 1b). The tightening force is large enough to ensure that the seam will not open during hammering and the deformation will occur immediately after the tight seam is hammered. Due to the huge area of pressed surface, the compression stress distributed on the pressed surface is very small and thus does not affect the experimental results. After hammering, the steel rods are separated and the 3D morphology of the pressed surface is measured by a ZEISS LSM 700 laser confocal scanning microscope. The data are fitted *via* OriginPro 2017 to find the effective boundary points of the raised plastic zone, and then these points are nonlinearly fitted using Wolfram Mathematica 10.2 [13,14].

To evaluate the reliability of tight hammering method, we dynamically monitor the tight seam near the impression during hammering *via* a dynamic strain monitoring system (AFT-0951 dynamic strain meter and BEM120-1AA-S-X30 resistance strain gauge) and record the whole dynamic strain process. During the dynamic mechanical test, the continuous surface and the tight seam are hammered under identical conditions, and the real-time tangential strain and radial strain at the place which is 2 or 4 mm away from each hammered points are measured using a dynamic strain device. The locations of strain gauges on the surface are shown in Fig. 1c. Points A_T–C_T represent the “tangential” positioning of strain gauges which measure the strain in the direction tangential to the hammered point. Points A_R–C_R represent the “radial” positioning of strain gauges which measure the strains parallel to the radius vector of the hammered point.

3. Results and analysis

3.1. *Morphology and analysis of the plastic deformation zone*

As shown in Fig. 2a, after the steel rods are separated, a raised zone appears on the pressed surface of steel rods, and then the flat portion in the middle of this raised zone is considered as the plastic deformation zone. The hammered surface exhibits an obvious raised deformation region, which is surrounded by a belt-shaped transition zone. The belt-shaped transition zone separates the deformed and undeformed area of steel rods. When the external stress of material is in excess of its yield strength, plastic deformation and elastic deformation will simultaneously occur. There is a balance between the stresses within the plastic deformation zone and the surrounding elastic zone. Hence, the balance will be broken and new balances will appear on the pressed surface of the steel rods when they are separated. Then, a raised plastic zone appeared below the impact point. According to the principles of mechanics, this phenomenon is closely related to the yield strength of material. The yield strength of steel rod determines the degree of springback when the external force is removed. Therefore, the steel rod with higher yield strength will exhibit more obvious springback.

The 3D morphology of cross-sectional surface is investigated by a ZEISS LSM 700 laser confocal microscope. Fig. 2b

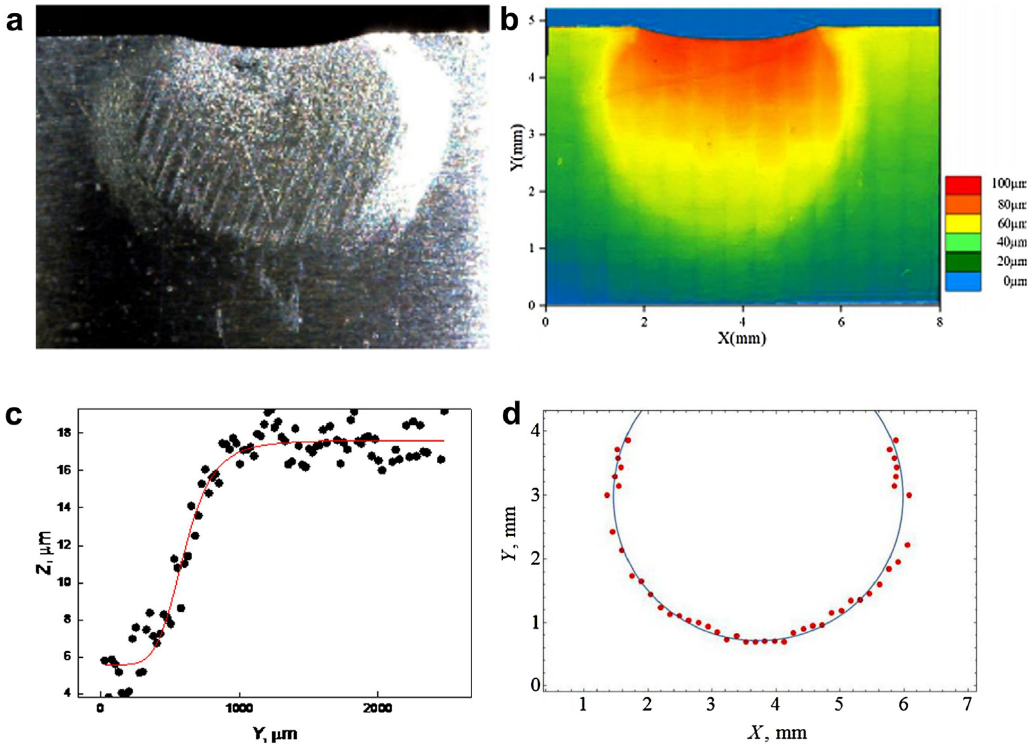

Fig. 2 – (a) The digital image of the raised deformation zone. (b) The 3D morphology of the raised zone. (c) The sagittal parallel scatterplot with the X value of 3.677. (d) The fitting results of effective boundary points on the sagittal parallel line of the raised zone.

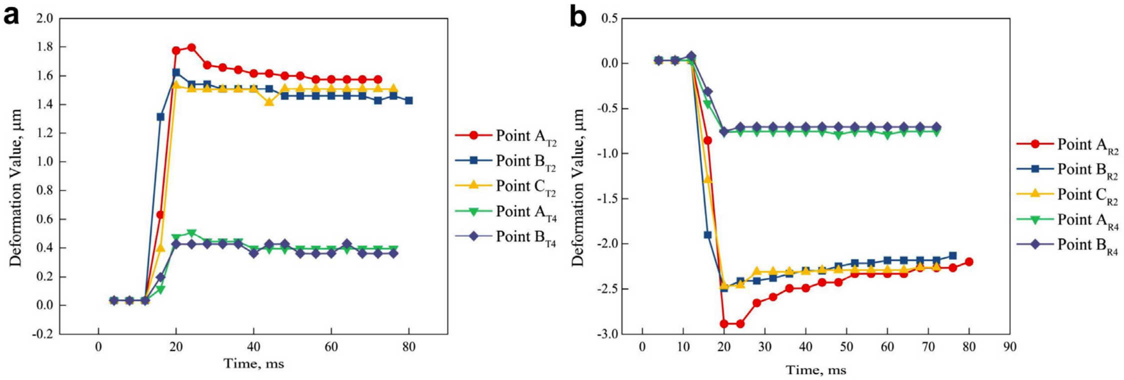

Fig. 3 – (a) Strain curve from strain gauges oriented tangential to circles centered at hammer impressions. (b) Strain curve from strain gauges oriented radial to circles centered at hammer impressions.

presents the 3D morphology of the raised zone caused by a SΦ11 spherical punch head under an impact stroke of 150 mm. It is obvious that the raised zone is circular in shape. The position near the hammer impression shows a higher-raised zone. The depth of the plastic deformation zone is approximately 3.5 mm. According to reference [13], the data of the raised deformation zone are then fitted using OriginPro 2017 to identify the effective boundaries of the raised plastic zone, with the corresponding curve shown in Fig. 2c. As shown in Fig. 2c, the S-shape curve is in good correlation with the experimental data. Based on reference [14], the obtained curve is further nonlinearly fitted *via* Wolfram Mathematica 10.2, with the result shown in Fig. 2d. There is a circle in Fig. 2d and its radius and center coordinates are 2.263 mm and (3.719, 2.978), respectively, indicating the circular boundary of the plastic zone.

3.2. *Dynamic strain tests*

As shown in Fig. 3a, all of the deformation values are positive, indicating that the strains in the tangential direction around the center point are tensile ones. As shown in Fig. 3b, all of the deformation values are negative, indicating that the radial strains around the hammered impressions are compressive ones. As shown in Fig. 3, the absolute value of deformation in the tight seam is slightly larger than that in the continuous surface, which is mainly because two steel rods restrain each other by friction and they move slightly during hammering, leading to a slight increase in the absolute value of deformation. However, the increase in peak deformation value at the tight seam is not evident, indicating that the pressed seam dose not separate and the raised zone of material is caused by the elastic recovery. The results above confirm that the plastic deformation zone formed on tight seam is very close to that on continuous surface. Therefore, the tight hammering method we offered is a reliable way to investigate the shape and size of plastic deformation zone formed by hammering.

4. Conclusions

The plastic deformation zones formed in Q235 steels after hammering is creatively investigated *via* tight hammering method. Mathematical simulation and analysis of the experimental data confirm that the boundary of the plastic zone is circular and the impact impressions are symmetrical. Thus, the shape of plastic zone formed by the SΦ11 punch is spherical. The dynamic strain monitoring results show that the method we offered is a reliable way to investigate the shape and size of plastic deformation zone of steels formed by hammering.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

This research does not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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