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Investigation of the stress conditions of U-bend 316L stainless steel after performing cold mechanical process

W.M.F.W Mohamad[1,2,*], M.Z. Selamat[1,2], B. Bunjali[3], H.M. Dom[1,2]

[1)] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
[2)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.
[3)] Department of Chemisty, Institut Teknologi Bandung, Jl. Ganesha 10 Bandung, Jawa Barat-Indonesia.

[*]Corresponding e-mail: farid@utem.edu.my

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ABSTRACT – This study reports on the investigation of the stress conditions of the U-bend 316L stainless steel through the cold mechanical process, starting with cold rolling of 0 up to 50% reduction in thickness and then, bending. The stress conditions; such as applied and residual stresses of the U-bend steel were obtained experimentally from the bending stress-strain curves and resulted curvature. It was found that the applied and residual stress has a higher value in the steel with a 30% cold reduction, which was about 257 MPa and 240 MPa, respectively.

1. INTRODUCTION

Cold rolling and bending have been used as a common cold mechanical process of metallic materials which covers most of the engineering applications. Past researches have proved that the cold deformation processes produce such amount of stresses. They have developed a great solution for the prediction of stress conditions, either as individual or combination of an analytical, simulation and experimental [1-2]. For the experimental solution, there were numerous preparation methods of the bent shape, as recommended by the ASTM standard. It was involved in the preparation of the various bent sheet metal, such as U-bend, V-bend, C-ring and bent-beam. The U-bend shape was selected since the stress conditions were considered unknown [3]. Furthermore, this solution was also applied to measure the residual stress in the sheet metals which were initially straight shape by measuring the resulted curvature of the bent shape. Zhang *et. al.* [4] and Tan *et. al.* [5] have produced an analytical solution that the residual stress was a sum of the stress before unbending and elastic spring back stress.

Therefore, this study was emphasized on the determination of the stress conditions of the U-bend steel through an experimental solution. The applied and residual stress was estimated from the bending stress-strain curves of the U-bend steel with a different level of the cold reduction. In addition, the related bending behaviors of the U-bend steel were also highlighted in this research.

2. METHODOLOGY

Experiments were carried out on 316L stainless steel (SS) with chemical compositions (in wt.%) of 316L [Fe, 16.61% Cr, 10.44% Ni, 1.048% Mo, 2.03% Mn, 0.02% C, 0.0022% S, 0.03% P, 0.571% Si, 0.28% Cu and 0.0221% N] as provided by the manufacturer. The test specimen with an initial thickness of 2.0 mm were unidirectional rolled to 0, 10, 30 and 50% reduction in thickness (%RT). Three sets of the specimen were prepared for each particular cold reduction. Then, the specimens were CNC milled to a dimension of 80.0 x 20.0 mm, with a hole of 10.0 mm in diameter on both sides. The bending process was done according to ASTM G 30-97, using a two stage stressing. In the first stage, the specimen was stressed to a U-bend shape using the bending jig, which was attached to the tensile machine: model Instron 8802 (US) system of 250 kN capacity. The process was subjected to a 3-point bend test with a constant speed of 1.0 mm/min. The second stage of the bending process was performed by manually stressing the specimen, and the U-bend shape was finally obtained.

A simple analysis of the U-bend steel was done before and after unbending using an image mapping techniques as shown in Fig. 2(a). It was used to measure the resulted curvature, in terms of the longitudinal deflection, D, lateral deflection, W and bend angle, α. The metallography analysis of the specimens was done using microscopy techniques. The specimens were cut to a reduced scale, approximately 8.0 mm from its maximum bending region. A standard metallographies technique was applied during the sample preparation.

3. RESULTS AND DISCUSSION

The bending properties of the U-bend 316L SS were characterized according to their bending stress-strain curves. Fig. 1 shows the curves of the U-bend steel with different cold reduction. At the initial stage, all the U-bend steel show a similar pattern, where the applied stresses were gradually increased with a higher strain rate. A large bending load was needed to transform the straight to the semi U-bend shape. Within this portion, the steel was elastically deformed before it reaches the ultimate bending stress.

After exceed this limit, the stress was rapidly dropped until the steel was permanently deformed to the U-bend shape. This was probably due to the formation of the inner cracks in the center of the U-bend steel as shown in Fig. 2(b).

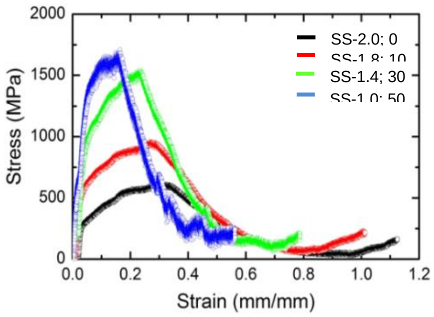
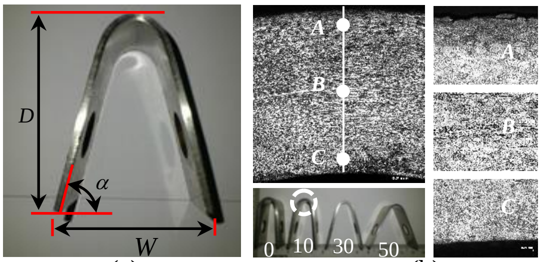


Fig. 1 Bending stress-strain curves.



(a) (b)

Fig. 2 (a) Image mapping techniques, and (b) the formation of inner cracks.

Another bending behavior of the U-bend steel was related to the spring back phenomena. Table 1 illustrates the resulted curvature of the U-bend steel before and after unbending condition using an image mapping techniques. The increment of *D* and reduction of *W* after unbending, with reflected to the condition before unbending, was closed due to the spring back. It means that the specimen with a higher cold reduction produces a greater spring back and a higher residual stress.

Table 1 The measurement of the resulted curvature.

Sample ID	%RT	After unbending			Before unbending
		D_a (mm)	W_a (mm)	α_a (°)	W_b (mm)
SS-2.0	0	37.55	20.10	85.32	15.00
SS-1.8	10	37.40	24.10	80.01	14.75
SS-1.4	30	36.35	30.60	75.51	14.05
SS-1.0	50	33.70	40.10	65.22	13.90

Furthermore, the stress conditions of the U-bend steel were investigated according to the stress after and before unbending condition. It was obtained from their bending load-displacement and stress-strain curves. Fig. 3 shows the stress of each of the U-bend steel. The stress before unbending refers to an applied stress, σ_{ap} at the maximum deflection of the U-bend steels. Whereas, the maximum deflection refers to the final displacement in longitudinal direction before unbending, D_b with a bend angle, α_b of 90° into the U-bend shape. The D_b values of all specimens were about 37.70 mm. As expected, the U-bend steel without cold reduction (0%RT) shows a lower σ_{ap} of about 161 MPa. The value was increased to 209 and 257 MPa for the U-bend steel with 10 and 30 %RT, respectively. However, the σ_{ap} was decreased to 218 MPa for the U-bend steel after extensively cold reduction to 50 %RT.

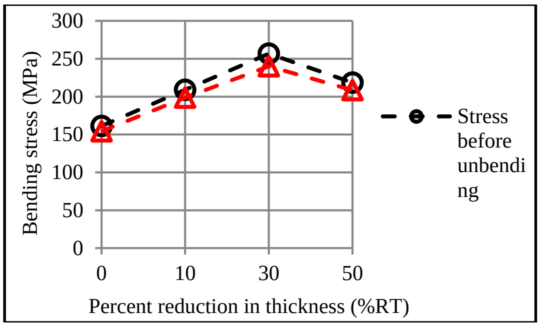


Fig. 3 The stress conditions of the U-bend steel.

The stress after unbending was closely referred to the residual stress, σ_{re}, as stated in the previous researchers [4,5]. From Fig. 3, the σ_{re} also shows a similar pattern with the σ_{ap} where the highest value was about 240 MPa for the U-bend steel with 30 %RT. In addition, the elastic spring back stress, $\Delta\sigma$ of all the U-bend steel have a negative value (where $\Delta\sigma = \sigma_{re} - \sigma_{ap}$). This was due to the nature of the spring back that it will be returned back to the previous bending path.

4. SUMMARY

The stress conditions of the U-bend 316 SS after performing cold mechanical process has been defined experimentally from the bending stress-strain curves and resulted curvature. It can be concluded that:

a. The processes were confirmly produced such amount of the residual stress. It has been preliminary predicted from the resulted curvature of the steel as a result of the spring back for each particular cold reduction.
b. The applied stress at the maximum deflection was higher than its residual stress. The highest value of the both stresses was obtained in the U-bend steel with 30 % cold reduction.

5. REFERENCES

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