Experimental and Analytical Evaluation of the Vibrational Stress Relief Process Parameters on the Steel Specimen Based on the Computational Model

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Abstract

The vibration stress relief process is currently utilized as a suitable alternative to the thermal stress relief method to reduce the residual stress of various alloys. In this study, a theoretical model based on the analytical equations is presented. The proposed model including the frequency, amplitude and the process time have been revised compared to the previously proposed models to make it more comprehensible and applicable. Thus, the assumed parameters including the number of cycles (duration), the strain rate (loading frequency), and the amplitude (loading value) are embedded in the model. Experimental tests measuring residual stress distribution by X-ray diffraction method are conducted on specific spots to compare the results with the experiments. An acceptable range of error (below 10%) has been observed between the theoretical and experimental results. According to the obtained results, the model has an acceptable performance for residual stress calculation after the process. According to the results, vibration amplitude has been about 19% more effective than the other parameters. In addition, increasing the amplitude has increased the affirmative effect of the frequency parameter by 38% compared to the other parameters. To further examine the presented model, the variations of the stress rate has been analyzed versus each influential parameter.

Keywords: Vibration stress relief, Computational model, Residual stress, Steel specimen

1. Introduction

Vibrational techniques are among the stress relief methods that have been used in various mechanical and civil structures to reduce residual stress. As scientists claim, short-term systematic vibrations can have the same effect as a long-term natural aging process [1-3]. The results of the study conducted by McGoldrick [4], Sędek [5], Lokshin [6] and Moore [7] on welded structures have shown that vibrational stress relief method can reduce the residual stress by about 70% in cast parts.

The studies conducted in the field of vibration stress relief are not limited to experimental evaluations and the theoretical aspects of the process have also been investigated [8, 9]. Kwofie [10] and Rao et al. [11] proposed a model to describe the state of plasticity in the vibrational stress relief process. This way, the effect of process parameters including vibration frequency, stress amplitude, amplitude, yield stress, and strain hardening rate were analyzed in the light of this model. Although the above models are well discussed, the practical validation of the model has not been presented in most of them and the complexity of the equation requires additional computational efforts to obtain the residual stress value.

The analytical method followed by Dawson [1] forms the basis of the equation presented in the present study. This equation has been used to account for the desired basic parameters to evaluate the amount of stress release. The comparison of these results has demonstrated an acceptable difference between experimental and computational results.

2. Methodology

2.1. Experiments

In order to validate the presented theoretical model, a specimen made of 1008-AISI was considered to be evaluated experimentally and theoretically. The intended experiments were carried out in three parts: imposing the initial stress distribution by applying torque according to a previous study

[12] (Fig. 1), vibrational stress relief, and residual stress measurement.

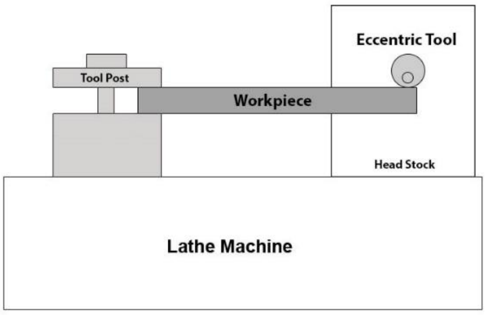


Fig. 1 Proposed vibrational stress relief configuration

2.2. Theoretical method

Distribution of the residual stress before the vibration stress generation has been described in the previous study [12]. The final model after corrections has been obtained for the cross section of the sample beam as follows.

$$\sigma_{fr} = \frac{3\delta_n E y}{L^2}\left(\left(\frac{\beta'}{n}\sum_{i=1}^{n}((-1)^{i+1}\times i)\right)\sin\left(\frac{y}{4h}\right)+1\right) \quad (1)$$

Where M_1 is the moment to impose the initial residual stress and M_2 is the moment for the first cycle of residual stress relief vibration, σ_{fr} is the residual stress distribution after applying M_2 (Fig. 2), σ_e is the yield stress of the material, I is the moment of inertia, c is half of the height of the cross-section of the beam, β beta is the ratio of the slope of the simplified diagram of strain-stress in the plastic section out of the elasticity modulus, h_1, h_2, and h are half of the height of the cross-section in the plastrc zone in the primary, secondary, and general state respectively, δ_n is the beam deflection of the nth cycle and β' is the ration of the slope of stress-strain diagram in the plastic section to the elastic section.

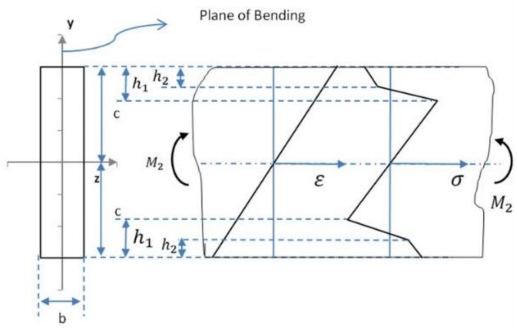


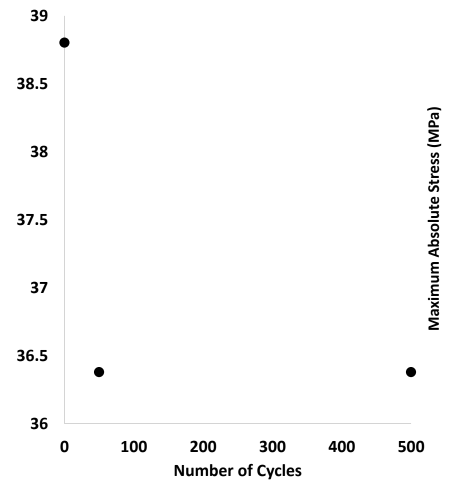
Fig. 2 Stress distribution while applying M_2 [1]

3. Results and Discussion

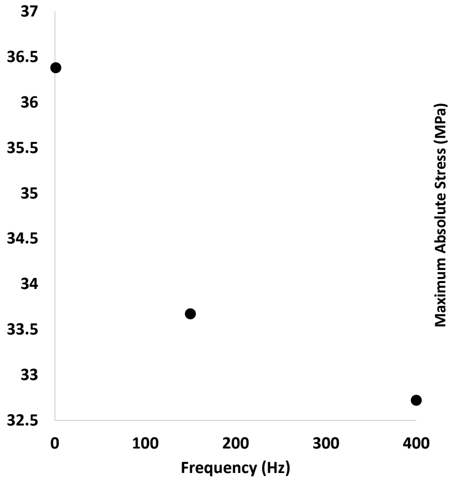
Fig. 3 indicates the effect of each parameter on the predicted maximum residual stress value along the y axis. As shown in Fig. 3-a and b, the change in the residual stress reduction behavior for the amplitude parameter has been different in terms of behavior and value compared to the other parameters. The range of the residual stress variations has been 40 to 240 MPa, which has occurred for 1 and 3 mm amplitude, respectively.

4. Conclusion

In this study, the theoretical model of the vibrational stress relief process has been developed and modified to include more parameters to analyze the process further. The presented model takes into account the effect of time (number of cycles), load (amplitude), and the frequency (strain rate) of the process. According to the results, the model has an acceptable performance in terms of calculating the distribution of the residual stress after the process compared to the experimental results. The amplitude has been about 19% more effective than other parameters based on the results, while the stability of the positive effect of the frequency parameter was about 38% compared to other parameters.



(a)



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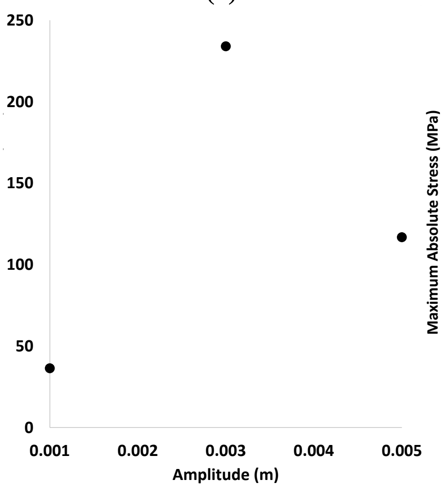

(c)

Fig. 3 Maximum absolute value of the residual stress calculated along the y-axis on the cross-section for (a) $\delta = 1\text{mm}, f = 1\text{Hz}$; (b) $\delta = 1\text{mm}, n = 10$; (c) $f = 1\text{Hz}, n = 10$

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