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CHABOCHE SINGLE MODEL CALIBRATION FOR BAUSCHINGER EFFECT

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Abstract. In this work a study of Chaboche single model for Bauschinger effect characterization was performed by using the Ramberg-Osgood relation to determine the Chaboche constants (C_1 and γ_1). A series of adjustment were made to obtain specific values, and from these values a curve fitting was performed to determine Chaboche constants. The analysis of Bauschinger effect was executed by finite element method and compared with experimental data available in the literature. The results showed good agreement in comparison to experimental analysis.

Keywords: Bauschinger effect, Chaboche model, Ramberg-Osgood, numerical model.

1 Introduction

The Bauschinger effect is a mechanical phenomenon that is normally related with to conditions where the yield strength of metal decreases when the strain direction is changed. According to Han *et al.* [1] when plastic deformation in one direction is followed by plastic deformation in the opposite direction, such as during cold forming, the internal stress distribution within the material changes with a resulting change in material properties. This directional strain hardening results in an increase in yield strength in the direction of the applied force and a drop in yield strength in the opposite direction. This drop in yield strength is known as the Bauschinger effect. Most founded in polycrystalline metals, Bauschinger effect is an important mechanical process depends on the plastic strain.

Related to Bauschinger effect, springback is an important issue for the sheet metal forming industry. Regard to the geometric change made to a part at the end of the forming process when the part has been released from the forces of the forming tool. As reported by Han *et al.* [1] the springback can be a major problem in producing sheet metal parts for a wide range of applications, such as automotive panels, aeronautical and naval applications, appliances, etc. Bauschinger effect has a significant influence on the metal behavior when subjected to cyclic deformations, although many researches have ignored the Bauschinger effect on springback modeling (Gau and Kinzel [2]).

The control of materials behaviors depends on the determination of a set of variables that are obtained from mechanical characterization tests. These variables are used for the constitutive model calibration in order to predict the materials behavior making the manufacturing process more accurate. Some numerical approaches for defining material parameters has been done by using Ramberg-Osgood relation in order to describe cyclic and monotonic stress strain curve, and for determining the Chaboche material constants (Basam *et al.* [3], Mostaghel and Byrd [4] and Karolczuk [5]). Others researchers has also shown the importance of Chaboche model calibration in numerical modelling. Moslemi *et al.* [6] used the Chaboche model to predict the uniaxial and biaxial racheting behavior of 316L stainless pipe and Yang *et al.* [7] evaluated large strain range with Chaboche combined hardening model.

In this work the main goal relies on defining the Chaboche constants for the stainless steel UNS S30100 by using Ramberg-Osgood monotonic relation. The Bauschinger effect for a Chaboche single model supported by numerical and experimental results is investigated. This paper is organized as follows: a brief review about the Bauschinger effect is introduced in Section 2, Experimental tests and material information are introduced in Section 3. The procedure employed for the calibration of the Chaboche is introduced in Section 4. Section 5 presents the numerical and experimental results. Finally, Section 6 presents the conclusions of this work.

2 Baushinger effect

The Bauschinger effect is an important mechanical phenomenon that occurs in metallic materials. This phenomenon is associated to a specimen when is subjected to a traction load followed by a compression load (Lemaitre and Chaboche [8]). According to Mataya and Carr [9] if the load is sufficient to cause plastic deformation in one direction, re-straining the material in the opposite direction result in a lower elastic. This process results in higher yield stress in traction (hardening), but softening in compression.

Figure 1 shows a scheme for the Baushinger effect. The yield strength under tension is σ_{ot}, if the same material is ductile and have been tested for compression, the yield strength under compression would be σ_{oc},. When the specimen is subjected to tension followed by compression, the yield strength will change in reversal loading A.

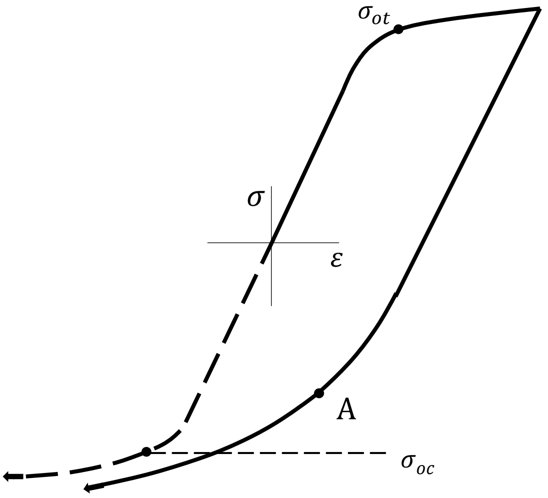

Figure 1. Schematic for the description of the Bauschinger effect.

The Bauschinger effect occurs due to the presence of residual stress resulting from the manufacturing process. The pile-up and discordance of grain boundaries would facilitate the dislocation of discordance in the opposite direction to the initial deformation. As the deformations occur the dislocation will be accumulated. In softening local back stresses could be remaining in the material, helping the dislocation at the reversal direction, and consequently the yield strength of the material is lower. By reducing the dislocation number means that the strength is also reduced. The yield stress results lower in the opposite direction compared to the strain obtained if the test had been continued in the initial direction.

In hardening, the reversal loading direction could produce dislocation with opposite signal from the same source that produces the slip-causing dislocation in the initial direction. Discordance with opposite signal generated by the reversal loading would annul the discordance initially formed, so the hardening is associated to increased displacement density. (Han *et al.* [1]).

The characterization of Bauschinger effect can be carried out through the equation the Eq. (1) and Eq. (2), where BE is the Bauschinger Effect and BEF is the Bauschinger Effect Factor.

$$BE = \frac{|A| - |\sigma_o|}{|A|} \tag{1}$$

$$BEF = \frac{|\sigma_o|}{|A|} \tag{2}$$

Equation (1) is the difference between the stress at reversal point and the yield stress at the reversal loading. A 0.05 % offset strain was used to determine the yield stress on reversal, because it is provide a better correlation than the conventional 0.2% (Han *et al.* [1]).

The Eq. (1) and Eq. (2) allow quantifying the Bauschinger effect and it is important to remark as closer σ_{ot} (yielding stress) and A (stress at reversal point) lower will be the magnitude of the Bauschinger effect.

3 Bauschinger experimental test

The experimental tests considering the Bauschinger effect for UNS S30100 stainless steel were performed in Solosando [10] and summarized herein. The tests were conducted by strain controlled, the specimens were strained to 1%, 3% and 5% for tension-compression tests, and strained to -1%, -3% and -5% for compression-tension tests. The chemical composition and the mechanical properties for the UNS S30100 are reproduced according Tab. 1 and Tab. 2, respectively.

Table 1. Chemical composition of stainless steel UNS S30100 (%). Solosando [10].

Cr	Ni	Mo	C	Mn	Si	P	S
17,7	7,9	0,25	0,05	1,44	0,28	0,03	0,03

Table 2. Mechanical properties stainless steel UNS S30100. Solosando [10].

σ_0 (MPa)	E (GPa)	L_{25mm} (%)	A_f (%)	ϵ_{ult} (mm/mm)
207 ± 3	$132 \pm 3{,}1$	$81{,}1 \pm 9{,}8$	$79{,}1 \pm 8{,}7$	$1{,}5 \pm 0{,}1$

The tests were performed according to ASTM E606-04 [11], in a servo hydraulic machine MTS with load capacity of 250 KN. All specimens were designed following the ASTM E606-04 [11] recommendations, in order to avoid the specimens against to the buckling phenomenon.

4 Calibration of Chaboche single model

For this proposed model traction and a compression test is required. The obtained plastic strain data from tension-compression testes are used to fit the Ramberg-Osgood curve. The procedure for identifying the Chaboche constants followed the standard Ramberg-Osgood plastic strain-stress characteristic as introduced in Karolczuk [5].

The Eq. (3) allows defining the strain hardening exponent (n) and the strength coefficient (K) by plotting $\sigma\ vs\ \epsilon_{pl}$ data and fitting the curve as shown in Fig. 2.

$$\sigma = K{\epsilon_{pl}}^{n} \tag{3}$$

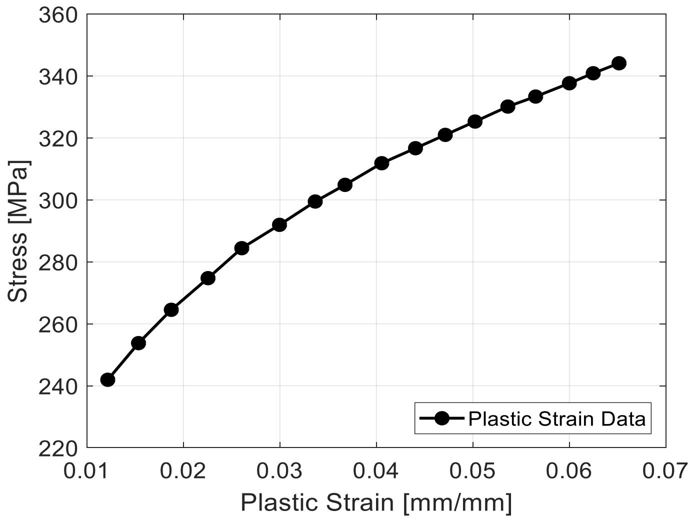

Figure 2. Stress vs Plastic Strain data.

Once the strain hardening exponent (n) and the strength coefficient (K) has been determined, the Ramberg-Osgood curve should be adjusted as show in Fig. 3.

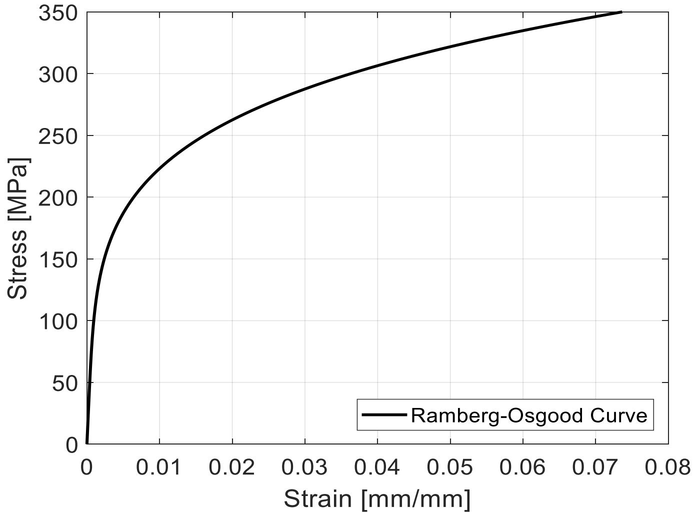

Figure 3. Ramberg-Osgood curve from adjusted parameters.

The identification of characteristic coefficients k, C_1 and γ_1 of the material is done in tension-compression from the stabilized loops which correspond different stress strain amplitudes. Following the step-by-step suggested by Lemaitre and Chaboche [8] the coefficients are given by:

i. Determine k approximately from the elastic domain (k is usually half the elastic domain size). This yield stress is higher than σ_{ys} because the initial modulus C is not infinite.
ii. From the graph determine the plastic strain range ($\Delta\epsilon_{pl}$).
iii. From the graph determine the stress range ($\Delta\sigma$).
iv. Plotting the $\frac{\Delta\sigma}{2} - k$ against $\frac{\Delta\epsilon_{pl}}{2}$ for three data, estimate the asymptotic order value corresponding to $\frac{C_1}{\gamma_1}$.

Determine the coefficients C_1 and γ_1 fitting the data given by step iv. Using the expression:

$$\frac{\Delta\sigma}{2} - k = \frac{C_1}{\gamma_1}\tanh\left(\gamma_1 \frac{\Delta\epsilon_{pl}}{2}\right) \tag{4}$$

5 Numerical and Experimental Results

The Chaboche constants were estimated by Ramberg-Osgood monotonic relation. Figure 4 shows the graph where Ramberg-Osgood tension and compression curve were plotted. A tangent line was applied on Ramberg-Osgood curve, beginning in tensile and compressive yield strength. The tangent line was used to capture the coincident points with the strain data (1%, 3% and 5%). These points are necessary to perform the step by step suggest in section 4.

Figure 4 shows the graph obtained by the procedure explained in section 4. A curve fitting was performed using Eq. (4) as reference, which allows to determine constants C_1 and γ_1.

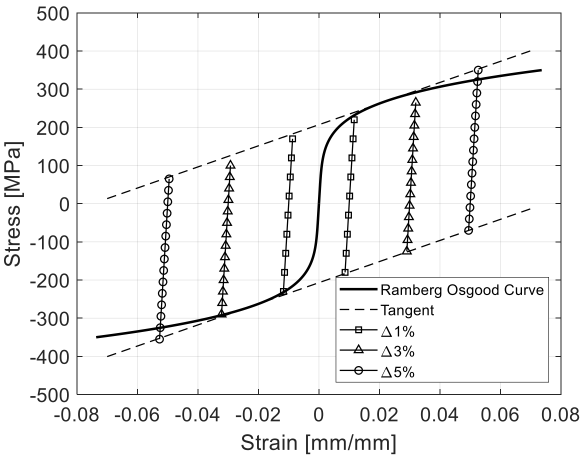

Figure 4. Ramberg-Osgood and adjusted parameters for Chaboche single model.

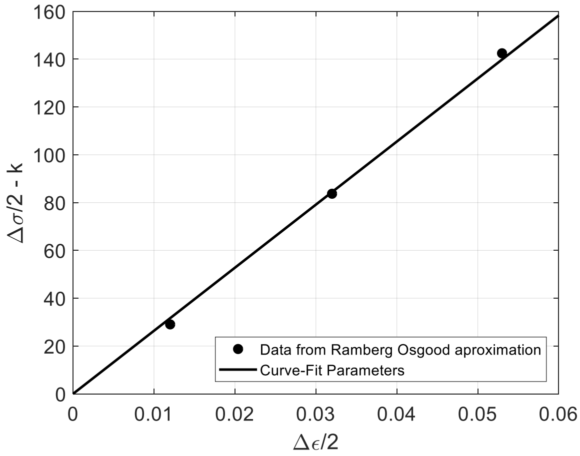

Figure 5. Curve-Fit Data from Ramberg-Osgood aproximation.

The numerical test was performed in finite element method, where the model had the constants obtained by numerical methods added in the material configuration. In order to verify the reliability of the single Chaboche model, the experimental and numerical results were compared by overlapping the curves. The curves were obtained from tension-compression and compression-tension, during strain controlled test of 1% (Fig. 6), 3% (Fig. 7) and 5% (Fig. 8).

The numerical Chaboche model showed good agreement for 1% and 3%, despite some variation in the C_1 and γ_1. For a wide strain range, like 5% (Fig. 8) the results in reversion did not match with good accuracy. In this sense a model of higher order should be more appropriated for predicting the yield stress at reversal point. Another alternative is the use of parameters derived from multiple stabilized cycles of experimental tests, that would result in better correlation for different strain ranges.

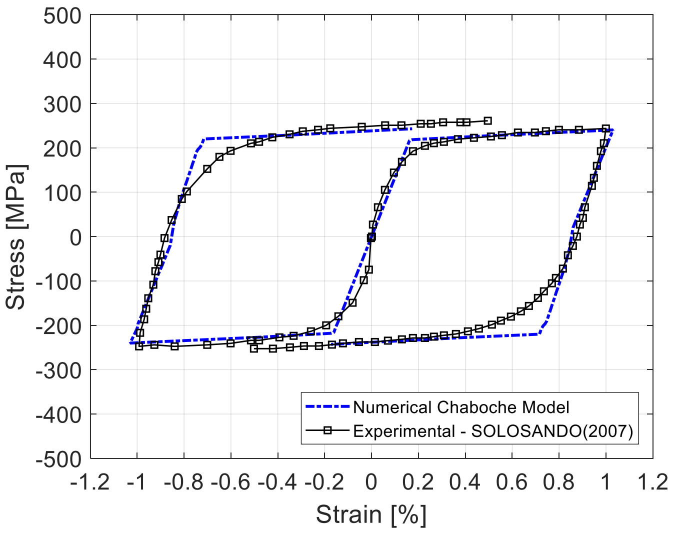

Figure 6. Comparison of experimental Bauschinger effect test data and numerical Chaboche model adjusted by Ramberg-Osgood, 1% strain.

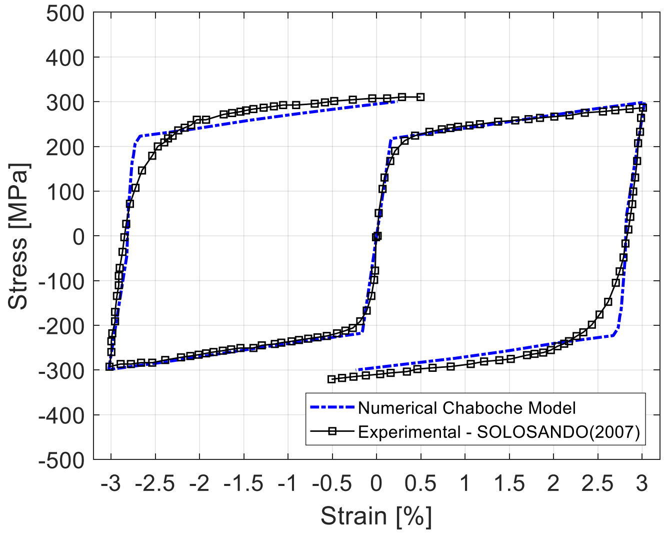

Figure 7. Comparison of experimental Bauschinger effect test data and numerical Chaboche model adjusted by Ramberg-Osgood, 3% strain.

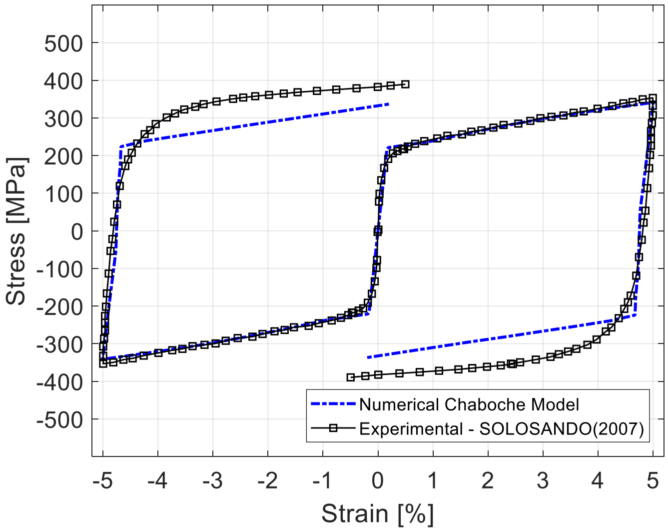

Figure 8. Comparison of experimental Bauschinger effect test data and numerical Chaboche model adjusted by Ramberg-Osgood, 5% strain.

Based on the results presented in Fig. 6, Fig. 7, and Fig. 8, it is possible to see in the yield zone did not have a smooth transition from the elastic to plastic zone. This observation is due to the low order of Chaboche modeling employed. In this sense, a curve-fit data obtained from several stabilized cycles should be more representative of behavior over a large strain range.

6 Final Conclusions

The methodology presented is an alternative way for determining Chaboche constants, being more appropriate for ductile materials due to similar behavior in tension and in compression. Tension-compressive symmetry behavior dispenses performing a series of cyclic strain controlled test to determine these constants.

As introduced in this work it was possible to determine the Chaboche single model by Ramberg-Osgood parameters with a satisfactory fit between experimental and numerical results. The results were more accurate for lower strain ranges, increasing the error as the strain level increased. Further efforts are in course to implement high-order Chaboche model to the present numerical methodology.

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