14th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2010, Mediterranean Cruise, 11-18 September 2010

ANALYSIS OF RESIDUAL STRESSES IN WIRE DRAWING PROCESSES

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ABSTRACT
Wire drawing is an operation in which the cross-sectional area of a bar, tube or wire is reduced by drawing it through a converging die. Materials processed by drawing are used for obtaining screws, bolts and wires, among others. The material processed by drawing is deformed plastically and because of the material strain hardening behavior, its mechanical properties (yield and ultimate strength) are improved. Due to the lack of homogeneity in the deformation, residual stresses appear within the drawn material. Residual stresses diminish the fatigue life, fracture strength and mechanical properties in corrosion ambient. While tensile residual stresses on the surface of the parts are undesirable, compression residual stresses reduce crack growth and hence, they increase the fatigue life of the part. In this work, the effect of the friction coefficient, the semi-cone angle of the die and the section reduction on the residual stresses introduced inside the wire is studied. In order to carry out this study, Finite Element Method (FEM) has been employed. Several FEM models with different process conditions have been simulated. In order to study the process, the drawing of a 5052 Aluminum Alloy considering strain hardening has been employed.
Keywords: Wire drawing, residual stresses, FEM

1. INTRODUCTION

In these last years, a large number of studies have been carried out on wire drawing [1,2]. Among them, some have the aim of getting to know the residual stresses that appear in the processed material due to the heterogeneity of the plastic deformation introduced throughout the cross-section [3,4]. In the present work, through the planning of a design of experiments composed of several finite element simulations, it is pretended to study the influence of several design factors such as the friction coefficient, the section reduction and the semi-cone angle of the drawing die over the residual stresses introduced in the material. The final aim is to achieve a distribution of residual stresses that minimises the risk of fatigue fracture, diminishes the crack growth and allows us to obtain improved mechanical properties in the material.

2. FINITE ELEMENT SIMULATIONS

2.1. Generalities

The finite element simulations were performed utilising the software MARC MENTAT 2008™, which allows us to solve non-linear problems. The employed formulation is of type Lagrange. The simulations were axisymmetric along with a rigid die and a deformable material. The process velocity was 30 m/min. In order to get the values of the residual stresses, an amount of 30 mm of material is processed and subsequently, the dies are separated so that these do not exert any pressure on it. The mesh is composed of 20 000 elements type quad 4, where these are two-dimensional elements and have four integration points. With the aim of decreasing the calculation time, the problem was divided into eight simpler parts that are calculated individually with the help of eight processors and, later on, these parts are coupled in order to give a joined solution. The friction model is of type Coulomb. All the freedom degrees of the matrix are restricted and a velocity condition in the external nodes of the material is applied in order to provide the force required to carry out the wire drawing process.

2.2. Hardening law of AA5052

The material hardening law is a very important factor to take into account in order to determine the values for the residual stresses [5,6]. In this way, tension tests for five samples of AA5052 were carried out with a total length of 300 mm and a gauge length of 200 mm. In order to homogenise the material properties and to eliminate any previous deformation, these samples were drawn to a diameter of 8 mm and subsequently, they were annealed at a temperature of 350 ºC during 4 hours, leaving them to cool slowly in the furnace. After performing the experiments, a Hollomon's model was used to fit the results for the tension tests. Equation 1 shows the hardening law obtained for the AA5052 aluminium alloy.

$$\sigma = 448.22\ \varepsilon^{0.35} \tag{1}$$

2.3. Design of experiments and geometry of the die

The geometry of the die is the main reason not only for the differences in the mechanical properties of the processed material but also for the possible defects such as central bursting. As well as the design factors for the DOE selected, there are two other important geometry parameters in the wire drawing die: the calibration length (which was 2 mm in the simulations performed) and the fillet radius between the conical zone and the calibration zone (where the latter was considered to be 25 mm in the simulations performed). These parameters can be observed in Figure 1.

Regarding the design of experiments, a central composite design (CCD) was selected. This consisted of a factorial design type 2^3, six star points located at the centre of the faces and one central point. The design factors selected were: the semi-cone angle (with a variation interval from 5º to 10º), the friction coefficient (type Coulomb and with a variation interval from 0 to 0.1) and the section reduction (from 10 % to 20 %). The different response variables were analysed using the software STATGRAPHICS CENTURION XV^{TM}.

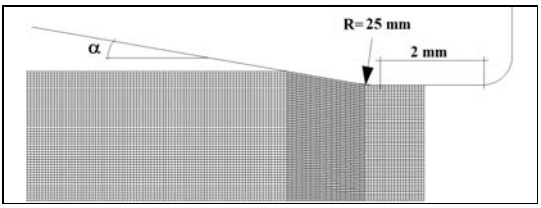

Figure 1. Die geometry and design factors selected.

3. OBTAINED RESULTS

3.1. Axial stress

It was obtained in all the simulations performed that the axial stresses are positive at the surface of the processed material and that they decrease as we move towards the central zone. Their value is zero at a point located at a relative distance from the surface equal to 0.3. Starting from this point, axial stresses become compressive. This can be observed in Figure 2.

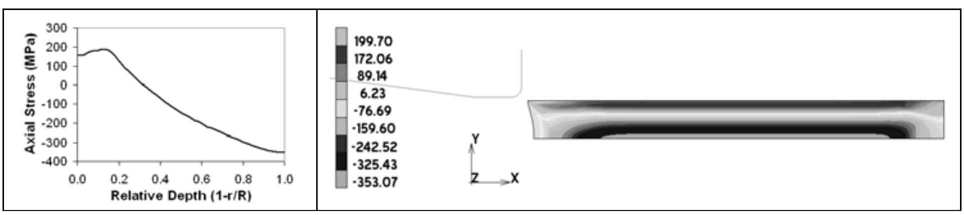

Figure 2. Axial stresses along the section.

A design of experiments with the maximum tensile axial stress as response variable was carried out. This variable was selected for the study because this residual stress is responsible for the fact that this zone in the wire begins to deform plastically before than at the centre when it is subjected to a load state. Equation 2 shows the model attained for the maximum tensile axial stress, where the value for the adjusted R^2 is 96.41 %. In Figure 3, its response surfaces can be observed.

$$\sigma_{\max axial} = 123.83 + 23.07\ \alpha + 176.69\ \mu - 7.68\ \%red - 0.29\ \alpha\ \%red - \\ - 2290.91\ \mu^2 + 0.17\ \%red^2 \tag{2}$$

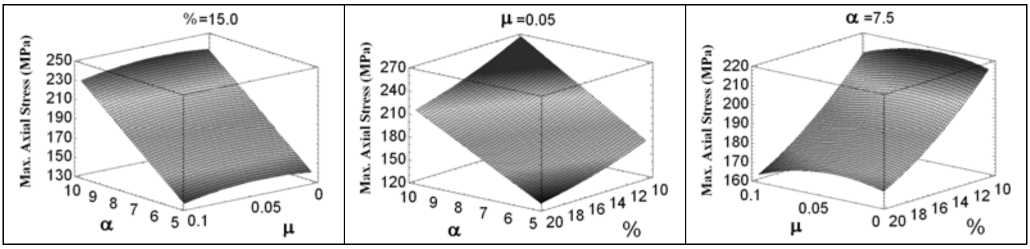

Figure 3. Response surfaces for the maximum axial stress.

From the attained results, it is possible to see that the semi-cone angle of the die is the most influential factor followed by the section reduction. The friction coefficient and the interaction effects between all the design factors are not statistically significant for a confidence level of 95 %. It can be observed that the maximum axial stress increases when the semi-cone angle is increased or when the section reduction of the processed material is decreased.

3.2. Radial Stress

The radial stress also varies throughout the cross-section of the processed wire, as can be observed in Figure 4. In this case, the value at the surface is zero and it decreases as we move towards the central zone. Because of the fact that the radial stress is compressive all over the section, its influence on the fatigue life and on the mechanical properties of the processed material is very limited in comparison to the previous case.

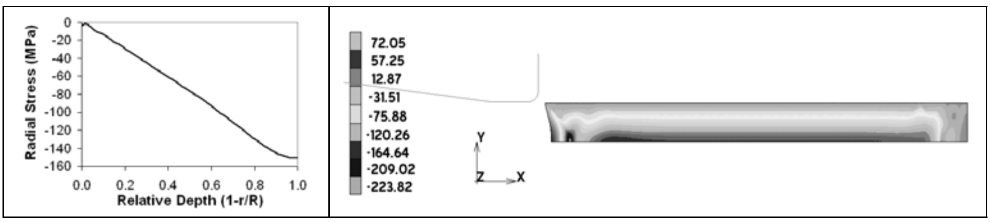

Figure 4. Radial stresses along the section.

3.3. Angular Stress

As is shown in Figure 5, the value for the angular stress is positive at the surface of the drawn wire and it is null at a point which is equidistant from the surface and the centre. From this point, stresses become compressive.

As in the case of the axial stress, a design of experiments with the maximum angular stress as response variable was carried out. Equation 3 shows the model attained for this variable, where the value for the adjusted R^2 is 95.39 %. In Figure 6, the response surfaces for the maximum angular stress can be observed.

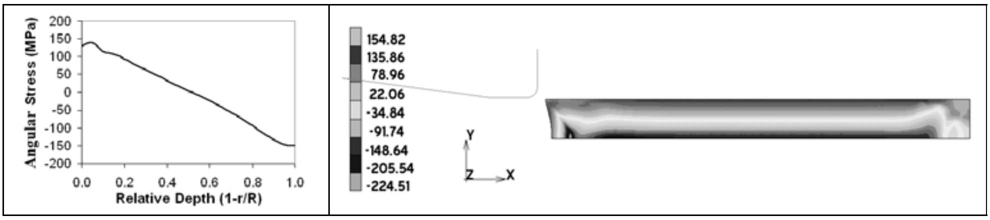

Figure 5. Angular stress along the section.

$$\sigma_{\max angular} = 25.72 + 21.41\,\alpha + 253.39\,\mu - 1.51\,\%red - 0.43\,\alpha^2 - 13.8\,\alpha\,\mu - \\ - 0.27\,\alpha\,\%red - 1446.9\,\mu^2 + 7\,\mu\,\%red + 0.11\,\%red^2 \quad (3)$$

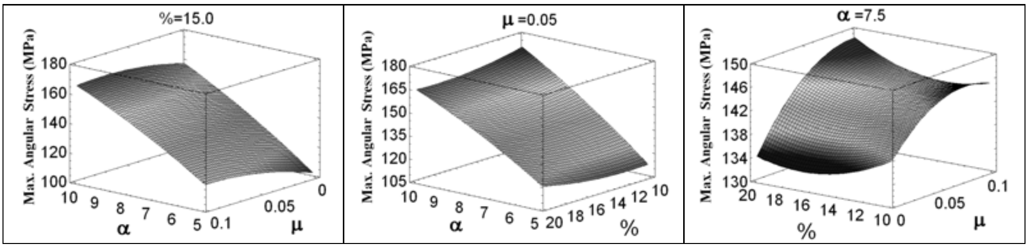

Figure 6. Response surfaces for the maximum angular stress.

In this case, the semi-cone angle turns out to be the most important factor followed, in second place, by the friction coefficient, whereas the section reduction and the interaction effects among the factors are not statistically significant ($\alpha = 0.05$). It is observed that the maximum value for the angular stress increases when both the semi-cone angle and the friction coefficient are increased.

4. CONCLUSIONS

A study on the wire drawing process was made by using both finite element simulations and design of experiments. The main aim was to reduce residual stresses, specifically those which are positive, by means of optimising the geometry factors, that is, the section reduction and the semi-cone angle of the wire drawing die, along with the friction coefficient.

It has been shown that the maximum value for the axial stress increases when the semi-cone angle is increased or when the section reduction is decreased. Furthermore, when both the semi-cone angle and the friction coefficient are increased, the maximum value for the angular stress increases.

5. REFERENCES

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