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EFFECT OF THE DIE GEOMETRY ON THE IMPARTED DAMAGE IN WIRE DRAWING

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ABSTRACT

Wire drawing is a plastic deformation process where a wire with circular cross-section is continuously reduced by making it flow through a conical converging die. As the material is drawn, it is plastically deformed and the mechanical properties of the material are modified. As the process is developed at room temperature and as a result of the introduced deformation, the yield stress of the processed material is increased due to the material strain hardening behaviour. Nevertheless, there exists a limitation in the reduction that can be applied in a single stage of drawing. This is related to the drawing instability and the imparted damage. The drawing instability appears when the process conditions become so hard that the drawing stress equals to the material flow stress and then the material necks in the drawing zone and the wire breaks. The damage the material undergoes is another limitation to the maximum reduction that can be made after a number of passages through different wire drawing dies. The material can be processed but due to process conditions, cracks, wrinkles and defects can appear on the surface or inside the wire. The external defects can be detected by a visual inspection but the internal ones are more dangerous because they are more difficult to detect. The mechanical properties of the parts manufactured from wires such as: strength and fatigue life will decrease drastically if defects have been generated during the manufacturing process. Due to the importance of developing the process correctly, the influence of the process conditions such as: die geometry and friction on the accumulated equivalent plastic strain as well as the imparted damage have been determined in this work. The drawing of a 5052 Aluminium Alloy considering strain hardening damage has been simulated by using several process conditions.

Keywords: Wire drawing, damage, FEM

1. INTRODUCTION

The wire drawing process is one of the most commonly-used plastic deformation processes in the industrial field, not only because of its high velocity process but also because of the mechanical properties that the material acquires once it has been processed. This process consists in reducing the cross-section of the processed material with the subsequent increase in its plastic deformation value. Diverse studies exist in relation to the drawing force required to carry out the process [1,2] and with respect to the plastic deformation accumulated. As a consequence of the residual stresses remaining inside the material, the wire drawing process can produce different types of defects [3]. External surface defects can be generally detected by visual inspection. However, in order to detect internal defects, it is necessary to employ other means such as ultrasonic testing. Therefore, it is very important to be able to predict in advance the existence of these as a function of process parameters such as: die geometry, material to be processed or drawing conditions. In the present paper, several finite element simulations were carried out in order to determine not only the accumulated plastic deformation but also the damage exerted on the material for the specific case of an aluminium alloy AA5052. The design factors studied in this work were: semi-cone angle of the wire drawing die, friction coefficient and percentage of section reduction. Furthermore, the size of the zone where the maximum value of damage is found was determined, which means assessing a valid measurement for the internal crack in the real material [4]. Finally, the standard deviation of the plastic deformation of the material was calculated in order to have a first approach for the homogeneity of its mechanical properties. With the aim of planning the number of simulations to perform so as to have a good approach in the results, the technique of design of experiments (DOE) was utilised through the software STATGRAPHICS Centurion XV™. In addition to this, in order to perform the finite element simulations, the software MSC Marc Mentat 2008™ was employed.

2. CHARACTERISTIC PARAMETERS

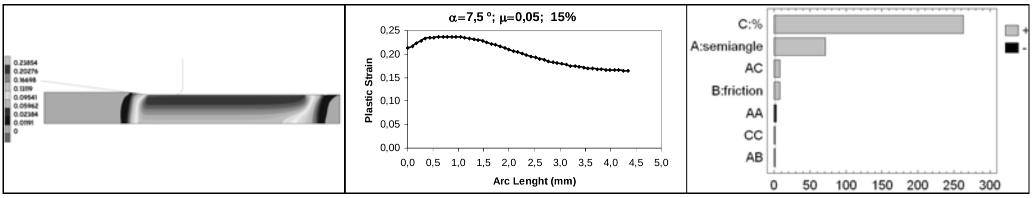
In order to achieve accurate results with a good approach to reality, it is necessary to get to know in advance the most influential variables involved in the process, where one of the most important is the hardening law of the material, in this case AA5052. The methodology followed in [5-6] has been used because from a tension test of the starting material, it is only possible to get information up to a deformation value of 0.2 (depending on the ductility of the material) and the ECAE process reaches deformation values $\varepsilon > 1$. This methodology consists in predeforming the material up to different known deformation values and subsequently, performing tension tests on each of the billets. The same wire drawing process is utilised to predeform the material up to a known value where this deformation value is known through finite element simulations. From each tension test, its plastic deformation part is selected and it is moved a deformation value equal to that accumulated in the predeforming process. The hardening law attained for AA5052 can be observed in Equation 1, where the selected fitting is of type Hollomon.

$$\sigma = 448.22\ \varepsilon^{0,35} \qquad (1)$$

As was previously-mentioned, the methodology of design of experiments was employed in order to select the number of experiments to perform. The design factors selected for this study were three with two levels for each of them. A central composite design (CCD) with 2^3 factorial points, six star points and one central point was used. The low and high levels for each of the factors were as follows: 5º and 10º for the semi-cone angle, 10 % and 20 % for the section reduction and 0 and 0.1 for the Coulomb friction coefficient. In the finite element simulations, the following characteristics were considered: a drawing velocity of 30 m/min, a billet length of 30 mm and 20 000 elements of type quad 4. When defining the contact conditions, the die was considered as a rigid body and the wire as deformable. Furthermore, an axisymmetric condition was taken for solving the problem.

3. TOTAL EQUIVALENT PLASTIC STRAIN RESULTS

Firstly, the results on the equivalent plastic deformation obtained for each of the DOE models will be shown. The mean value and the standard deviation of the deformation along the cross section were calculated in order to have a measurement of the homogeneity. Figure 1 (a) shows the value of the plastic deformation obtained for the wire in the finite element simulations. As could be expected, this value is higher at the periphery of the wire and it diminishes as one moves towards the central zone. Figure 1 (b) shows how the plastic deformation varies from the external zone to the internal zone for a specific cross section obtained from the simulation corresponding to the DOE central point.



a) Equivalent plastic strain

b) Strain distribution along the cross section

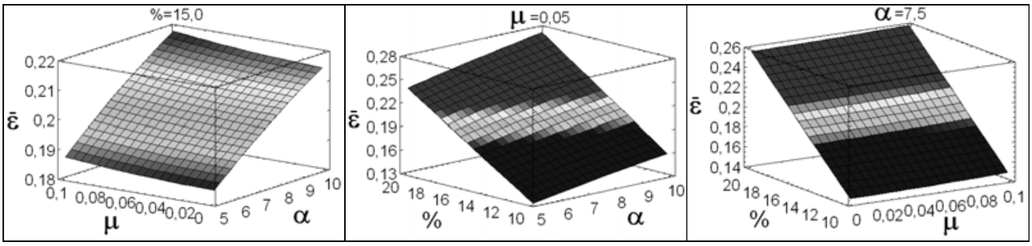
c) Strain Pareto chart

Figure 1. DOE results for the total equivalent plastic strain

Equation 2 shows the model attained for the mean value of the plastic deformation, where the adjusted R^2 statistic turned out to be 99.98 %. The model finally selected was that with the highest value for the adjusted R^2.

$$\begin{aligned}\bar{\varepsilon} &= 0.000231955 + 0.00687344\,\alpha + 0.01672\,\mu + 0.00922492\,\%red - \\ &- 0.000214109\,\alpha^2 + 0.00224\,\alpha\,\mu + 0.000151\,\alpha\,\%red + 0.0000234727\,\%red^2\end{aligned} \tag{2}$$

In Figure 1 (c), the Pareto chart for the estimated effects of the plastic deformation can be observed, where those most significant, arranged in importance order, are: the section reduction percentage, the semi-cone angle of the die, the interaction between them and the friction coefficient. The variation of them can be observed in the response surfaces depicted in Figure 2. As could be expected, when the value for the section reduction is increased, the value for the plastic deformation increases strongly. The same effect occurs with the semi-cone angle of the die. Nevertheless, with respect to the friction coefficient, the increase in the plastic deformation is vey low when it is increased, at least within the selected interval.



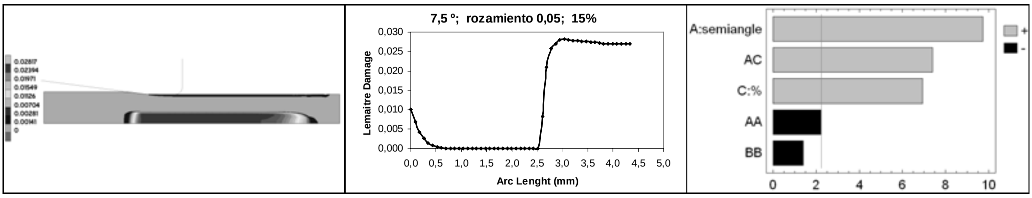
a) Friction coeff. vs. semi-angle b) Reduction vs. semi-angle c) Reduction vs. friction coeff.

Figure 2. Surface responses for the total equivalent plastic strain

Regarding the standard deviation of the plastic deformation, the attained results are practically the same, obtaining in this case for the ANOVA table the same significant factors and in the same order as well. The highest value for the standard deviation is 0.05 and it was given in the case of the model with a semi-cone angle of 10º, a section reduction of 10 % and a friction coefficient of 0.1. The most remarkable result is that the standard deviation decreases when the section reduction is increased.

4. LEMAITRE DAMAGE RESULTS

As was mentioned above, from the damage value one can estimate the possible appearance of cracks in the wire. In this case, it can be pointed out that the internal cracks are the most difficult to detect. Once the DOE planned simulations were carried out, the damage distribution along the longitudinal section of the wire was assessed, as can be observed in Figure 3 (a). In the same way, the damage imparted to the material depicted for the cross section of the wire in the model corresponding to the central point of the design can be observed in Figure 3 (b). The maximum value for the damage is located at the central part of the wire, where this value decreases up to zero when one moves outwards although there is a slight increase at the periphery.



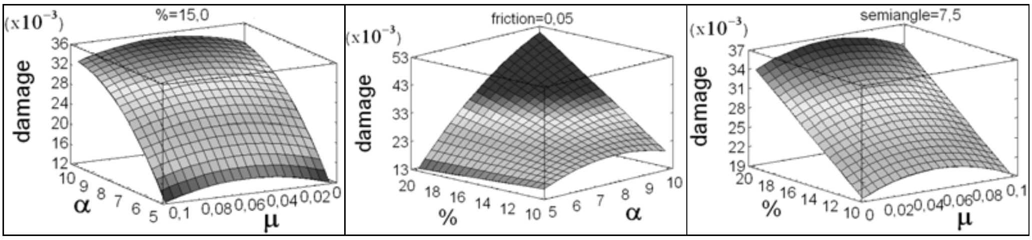
a) Lemaitre damage b) Damage distribution along the cross section c) Damage Pareto chart

Figure 3. DOE results for the Lemaitre damage

Equation 3 shows the accumulated damage model obtained with an adjusted R^2 statistic of 99.98 %.

$$D = 0.0134795 + 0.00400161\,\alpha + 0.109382\,\mu - 0.00377405\,\%red$$
$$- 0.000691127\,\alpha^2 + 0.0006991\,\alpha\,\%red - 1.09382\,\mu^2 \qquad (3)$$

Figure 3 (c) shows the Pareto chart for the estimated effects, where the most remarkable results are that the friction coefficient is not significant for a confidence level of 95 % and the semi-cone angle is the most influential factor. Figure 4 show the different response surfaces for the damage as a function of the three previously-mentioned design factors.



a) Friction coeff. vs. semi-angle b) Reduction vs. semi-angle c) Reduction vs. friction coeff.

Figure 4. Surface responses for the Lemaitre damage

In Figure 4, it is shown that when the semi-cone angle is increased, the level of damage increases quickly, whereas in the case of the friction coefficient, there is an initial increase in the damage and subsequently, it decreases starting from the central point of its work interval. An important point is to determine the width of the central zone of the wire where the material achieves the highest value of the damage (see Figure 3 (b)). The factors having the most influence on the width are the percentage of reduction and the semi-cone angle of the die, both with a similar level of significance. As the semi-cone angle increases, the size of the damaged zone decreases, whereas the contrary effect occurs in the case of the section reduction. The friction coefficient has a little influence and when its value is increased, the size of the damaged zone diminishes.

5. CONCLUSIONS

In the present work, the effect of several geometry parameters on the wire drawing process has been studied. From the DOE analysed, it is obtained that, within the study interval, the most significant effect on the plastic deformation is the section reduction, followed by the semi-cone angle of the die and the friction coefficient although this to a lesser degree. Nevertheless, a high value of plastic deformation in the material can lead to an excessive level of damage inside the wire. The accumulated damage mainly depend on the semi-cone angle of the die and, to a lesser extent, on the percentage of section reduction, being the effect of the friction coefficient very low.

6. REFERENCES

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