Kinematic and sensitivity analysis of rotary forging process by means of a simulation model

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ABSTRACT: Nowadays, due to the environmental regulations, the automotive market is demanding more complex components and the utilization of new materials. In this context, and due to its wide range of advantages, rotary forging technology is a very promising metal forming alternative to the conventional forming techniques. In this paper, an analysis of the material, the stress and strain has been realized, in order to show a comparison between conventional and rotary forging and to understand the mechanisms of rotary forming.

Key words: Rotary forging, automotive, simulation, incremental forming, bulk metal forming, FORGE©.

1 INTRODUCTION

We know as rotary forging an incremental manufacturing process that, based on the principle of continuous uniaxial pressure and using rotational movements in the dies, obtains net-shape revolution geometries from a “billet” as raw material. The most competitive advantages compared to the conventional forming techniques are the reduction of the forging force, the strong effect on the mechanical properties, the increment of the tensile and yield strengths and the accuracy of the obtained sections.

Prior to apply the incremental bulk metal forming to automotive industrial parts, a preliminary study has been done in order to understand the mechanisms of rotary forming and to show the main advantages versus the conventional forming. The study has been done using the commercial code FORGE©, a software dedicated to simulation of hot, warm and cold forging of both 3D parts and 2D geometry parts.

2 SIMULATION MODELS

Taking into account the kinematic, the following cases (Fig. 1) have been selected to achieve a simulation model computationally efficient, using relative movements in the dies to replace the turn of the material, which increases too much the CPU-time.

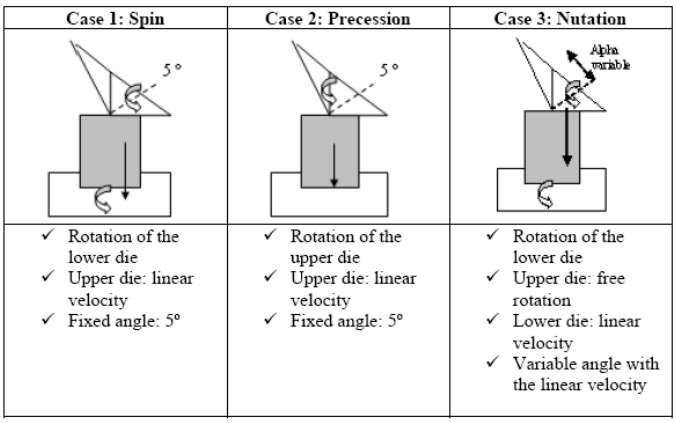

Fig. 1. Kinematic cases

Furthermore, the case 1 (spin) has been modelled turning the main and the nutation shafts both in the same as in the opposite sense.

As a first approach, the study began analyzing the five following models:

1. Case: Conventional forge
2. Spin case, with turns in the opposite direction
3. Spin case, with turns in the same direction
4. Precession case
5. Nutation case: variable angle

To develop the analysis, an upsetting process with a plain lower die and a plain conical upper die with a slope angle of 5º has been chosen.

Concerning the geometry of the model, the dimensions were a billet of ∅30 mm x 56 mm, which represents a ratio of 1'86. Having a 56 mm height, 10 mm of them are destined to fix the billet in the lower die.

The material selected is AA6061 aluminium at 480°C, the model is isothermal and Coulomb’s law has been used as friction law.

Thus, using these simulation models the following variables have been analyzed:

- Material fibers
- Plastic strains
- Von Mises stresses
- Forging loads

The following sections show, at first, an analysis of process in the case of fixed angle. Then, the differences with the variable angle have been studied.

3 PROCESS ANALYSIS

The results for each of the mentioned above variables are shown.

3.1 Fixed angle

3.1.a Material fibers

In each case, the fibers rotate due to the nature of the process itself (figure 2). However, the case of “spin” showed very good results. In this case, the lower die and the material rotate in one sense and the upper die turns in the opposite sense, obtaining a fiber without cuts and folds and getting a further upsetting compared to the same process conditions using conventional forge.

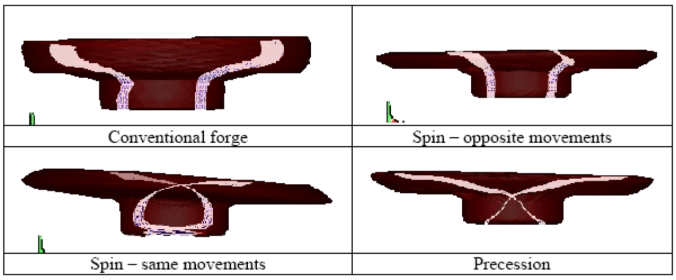

Fig. 2. Material fibbers

3.1.b Strains

As shown in Figures 3 and 4, the strain obtained in the spin case is higher than that for the conventional forge. As Fig. 3 shows, in traditional forge it would not be possible to obtain a similar strain, because in the outer zone an accumulated damage that would cause external cracks occurs. It is important to emphasize that the strain obtained is different in the four cases, being the most uniform the one corresponding to the “spin – opposite direction” case.

In the case where the rotational movements have the same sense the piece separates from the lower die, while in the precession case localized excessive-strain zones are generated, which predicts damage of the material. These processes will be more exhaustively studied in the future, in order to get a better understanding of the deformation mechanisms.

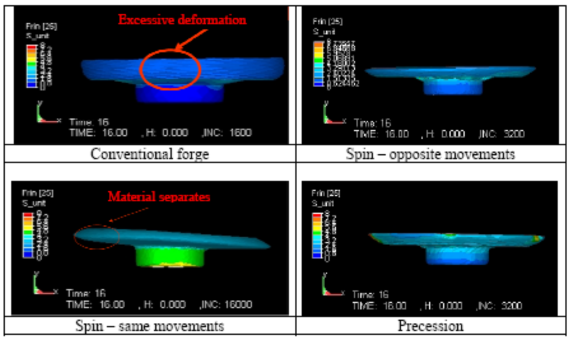

Fig. 3. Equivalent strains. Side view

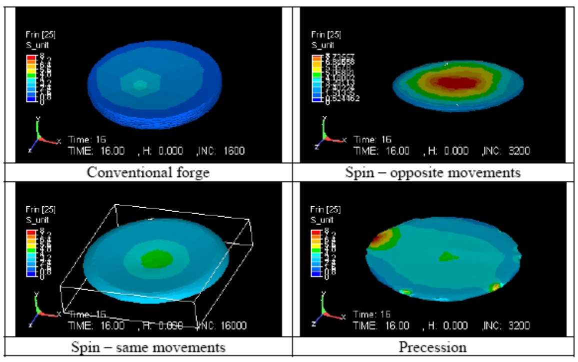

Fig. 4. Equivalent strains

3.1.c Stresses

Regarding the stress distribution (Fig.5), there is a clear dependence on the angle in the plastification area. Besides, the higher values occur in the spin and precession cases, which provide more hardness to the material.

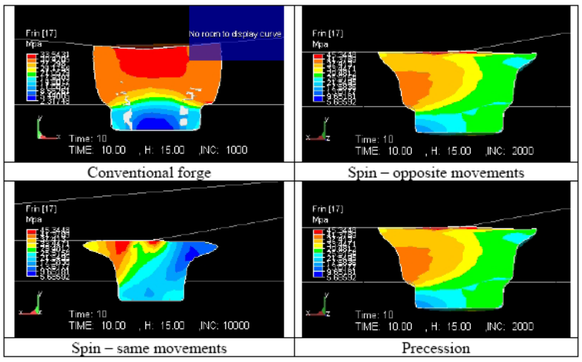

Fig. 5. Von Mises Stresses (MPa) in t=10 seg

3.1.d Forming loads

The most important advantage of the rotary forging is the reduction in the forging load (Fig. 6). This reduction is due to the contact area between the dies and the material, which is less than that in the conventional forging. Besides, in this new technology the nutation angle has a high influence in the forging load.

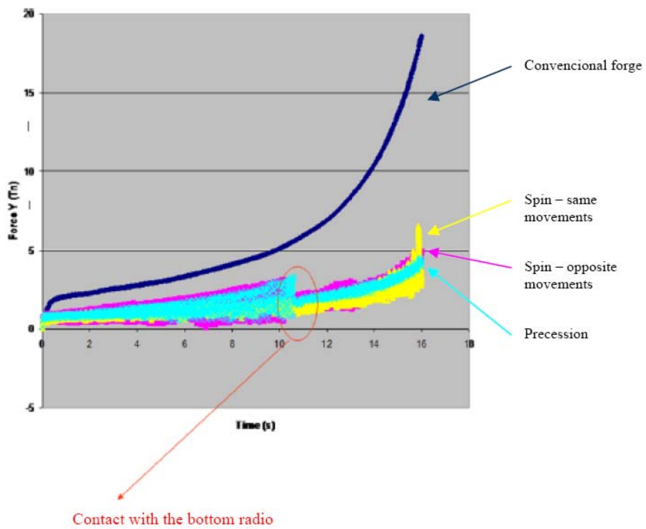

Fig. 6. Forces in upper die (Tn) comparison

As Fig. 6 shows, the loading force obtained in all processes is the third of that in the conventional forging, allowing the utilization of smaller and cheaper equipments.

3.2 *VARIABLE ANGLE*

The change in the angle during the process allows manufacturing more complex parts. Taking into account the best results obtained in the study above with the spin case, it was made a comparison with the variable-angle case.

First of all, the plastification area that appears in one step is larger in the variable-angle process, especially in terms of height. This fact is due to the high influence of the angle during the deformation process. Figure 7 shows the contact in the piece and the stresses generated, in a cutting plane, in both cases.

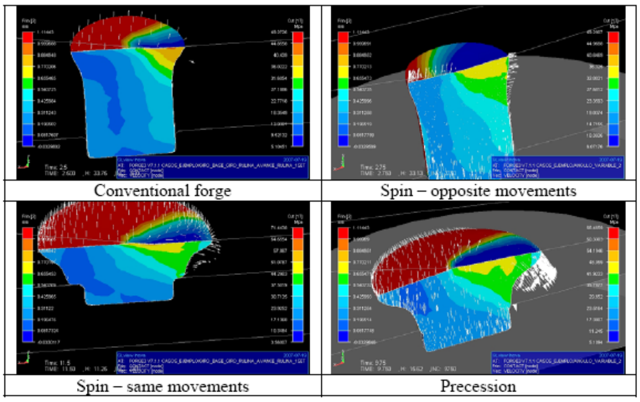

Fig. 7. Contact in the piece and Von Mises stresses (MPa) in a cutting plane

Besides, in order to understand better the mechanisms of deformation of the material, an analysis of the material speeds during both processes has been performed.

In the spin process and for an instant of time, the higher speeds are reached in the middle of the contact area, showing a triangular distribution. However, in the variable-angle case this triangular shape appears in a contact zone which is two times the previous one (Fig. 8).

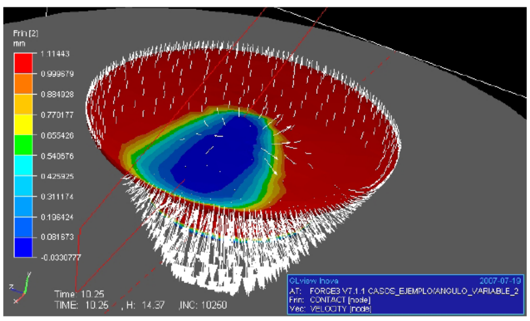

Fig. 8. Variable angle process. Contact area (in blue) and velocity distribution

By the other hand, due to the rotary process whirlwinds in certain areas of the material arise, being bigger effect in the case with fixed angle (Figure 9). In the variable-angle case more zero-speed zones arise.

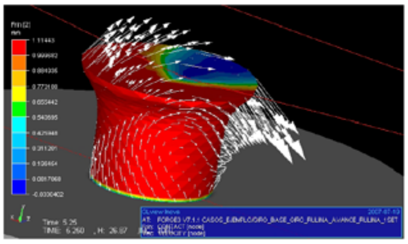

Fig. 9. Velocity evolution. Case: Spin – opposite movements

4 SENSITIVITY ANALYSIS OF PROCESS WITH FIXED ANGLE

Taking into account the above analysis, we can consider spin process the optimum one. After this case, an analysis of the influence of different process variables was performed, in order to eliminate defects and/or reduce forming loads.

In this context, the following variables are considered as the most influentials:

- Rotation speed
- Linear velocity
- h/∅ ratio of the initial billet
- Nutation angle

The following graphic shows that an increase in the angle is the change that involves a higher reduction in the load:

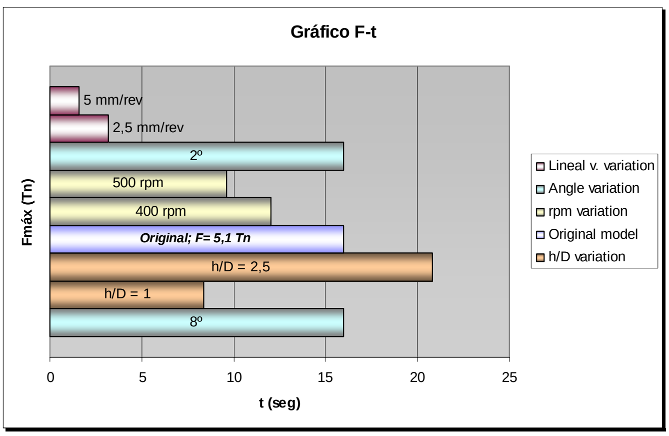

Fig. 10. Sensitivity analysis. Case: Spin – fixed angle.

5 CONCLUSIONS

After this study, it can be concluded that, generally, the spin process (fixed angle) with opposite rotational movement is the one that gives better results considering material fibbers, stresses, and strains. Nevertheless, there are not significant differences between the rotary cases in terms of forming loads.

Concerning to the sensitivity of process variables in the maximum load in this process, it has been found that the greatest influence is determined by the nutation angle or by the linear velocity, while the ratio h/∅ (height/diameter) or rotational speed do not affect significantly.

Furthermore, the rotation processes have less probability of failure (cracks) because the compression state is reached with an incremental process, allowing greater upsettings. However, it is important to consider the buckling in case of using high h/∅ ratios, which can cause wrinkles in the final piece.

ACKNOWLEDGEMENTS

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