

STUDY OF SIMULATION OF FORMING PROCESS TOWARD AN OPTIMIZATION PROCEDURE OF THE PROCESS

Ibrahim Khoury
Pascal Lafon
Laurence Giraud-Moreau
Carl Labergère

Charles Delaunay Institute, Laboratory of mechanical system and concurrent engineering.

University of technology of Troyes

12 Rue marie Curie, BP2060, 1000 TROYES France.

Phone : 0033325715671 – fax : 0033325715675

ibrahim.khoury@utt.fr

pascal.lafon@utt.fr

laurence.moreau@utt.fr

carl.labergere@utt.fr

Abstract:

Nowadays the computer simulation is used in the metal forming (stamping, forging, hydro-forming...) to reduce the use of the experimental investigation and tests required in a real tryout process.

A good simulation requires the knowledge of some data to give information about the mechanical fields: constraint, deformation, damage, temperature, damage and the total energy of deformation. The definition of the forming process needs to choose the initial form. The initial form is defined by the industrial from his industrial background. This operation requires a lot of iteration to be achieved correctly in order to obtain the optimal parameters of the initial form. The importance of simulation is not to replace the blacksmith in the development of its tools, but to bring a support to him.

In the Mechanical System and Concurrent Engineering Laboratory (LASMIS) a finite element package has been developed to solve elastoplasticity problems with ductile damage in large deformation. This package allows realizing numerical simulation of metal forming processes by using Abaqus/Explicit solver coupled with user material routine and an adaptive bidimensional mesher BL2D. One of our principal objectives is to develop a step of forming integration coupled with an optimization procedure in order to obtain the optimal parameters of the process.

Key words: Optimisation, damage distribution, forming process, numerical simulation.

1 Introduction

In an environment of increasing international competition where countries with lower production costs quickly catch up technologically, new thinking is required in order to meet the competition. Nowadays the computer simulation is used in the metal forming (stamping,

forging, hydro-forming...) to reduce the use of the experimental investigation and tests required in a real tryout process.

Forging is the process in which metal is deformed plastically by the application of pressure (we lose the elasticity of the metal at the forging temperature). Forging changes the shape and the properties of the metal because it improves its structure by refining the grain size.

Nowadays simulation is increasingly used by companies as an efficient tool in order to optimize metal forming processes plan before their physical realization.

In this paper we present a finite element package that has been developed in LASMIS to solve elastoplasticity problems with ductile damage in large deformation [1], [2]. We also present an SADT activity chart that highlights the input, the output and the control parameters of the forming process simulation in each step. Then we present some recent articles talking about the simulation of forming processes and we discuss the choice of the optimization variables based on the industrial needs and on the input parameters highlighted in the activity chart. Finally we show the importance of some parameters on the forming process by presenting an example for which we analyze the influence of the geometry of the initial form on the damage of the forged part.

2 Process and industrial needs:

The forged pieces are most of time under treated because the big companies give their design to specialist companies in forging to obtain their desired forged pieces. The client provides the plan of the final piece the blacksmith and charges him to satisfy the specifications. The blacksmith has to define his output which is the final piece that called rough forced. This rough forged is not the final piece desired by the client; the operation consists of a machining oversize. It is necessary to increase the dimension of the rough forged which must be taken again later. It is obvious that this machining oversize must be minimal in order to minimise the cost of material and machining.

Relative to the blacksmith, a small change in the form or dimensions done by the blacksmith can involve important variations in the results. Lots of criterions should be taken into account by the blacksmith:

The first criterion is to obtain good forged piece which means without default which means correct filling, without crack and shrinking. But how we predict the defects? The holders of the "simulation" approach suppose, basis on the analytic theories of mechanics, they are capable of predict the way in which the part deform between the matrices. On the other the holders of the approach "expert systems", hand suppose that there is a know-how in the profession and seek this know-how and formalize it to make it utilisable.

The second criterion is to use the necessary effort of forging to decrease as possible the wear of the tools. In other hand manufacturer should accurately predict the material flow, determine the filling of the die, predict if laps or other defects exists.

There are lots of typical process design constraints in industry like maximum available press load capacity and press speeds, material utilization and cost. The simulation brings a support for the blacksmith in the development of its tools. It is used to help him to satisfy the

specifications by defining the initial form or geometry of the piece if he knows the form of rough forged.

3 Existing Tools and SADT Activity Chart of process simulation

Problems associated with finite element simulation of the forming processes are characterized by large elastoplastic deformations, evolutive contact with friction, physical (plasticity, hardening, damage, temperature, etc.) and geometrical non linearities inducing a severe distortion of the computational mesh of the domain. The reliability and the performance of such a simulation are based on different types of tools: theoretical (constitutive relations representing the physical phenomena), numerical (algorithms to integrate the ODEs, schemes to solve non-linear systems PDEs, etc.) and geometric (representation of the object shape, finite element discretization or meshing, remeshing and adaptive meshing during the simulation). Theoretical aspects (plasticity with damage models), and related numerical aspects have been widely developed for many years, and performing tools have been proposed [3]. Concerning geometric aspects, the 2D or 3D object representations, as well as the initial finite element discretization, have also given rise to many development efforts [4]. A technique of adaptive remeshing for problems in large elastoplastic deformations, taking into account the ductile damage, has been proposed in the laboratory [5]. Numerical simulations of various metal forming problems have validated the proposed approach and proved its efficiency.

Finally, a finite element package has been developed to solve elastoplasticity problems with ductile damage in large deformation. This package allows realizing automatically numerical simulation of metal forming processes. Figure presents the main steps of the process simulation with in a IDEF0 representation. The global resolution of the coupled system is carried out by using Abaqus/Explicit solver coupled with user material Umat routine. An adaptive meshing and remeshing procedure using BL2Dadaptive mesher is used in connection with ABAQUS solver in order to enhance the numerical efficiency. For the simulation of 2D metal working processes a special procedure (schell script) has been developed in order to execute automatically ABAQUS step by step together with adaptive meshing methodology. At each load increment, and after the convergence has been reached, the overall thermo-mechanical fields as well as the new equilibrium configuration of the system composed by the deforming part and the rigid tools are known. An error estimation subroutine is called in order to check if any of the geometrical or physical error estimators is fulfilled. A geometric size map and a physical size map are defined according to each error estimator. In order to adapt the mesh element size with respect to the damage, a second physical size map is defined. During this stage, fully damaged elements are eliminated. A unique size map is finally generated from the intersection of the three size maps. The mesher BL2D is then called in order to remesh adaptively the deformed part with respect to the size map. The thermo-mechanical fields are transferred from the old to the new mesh thanks to the classical interpolation techniques keeping in mind the killed elements and the next loading step is worked out by calling ABAQUS solver. The SADT activity chart presented on figure 1 highlights the input, the output and the control parameters of the forming process simulation. The input parameters coloured in red will serve as optimization parameters for the forming process.

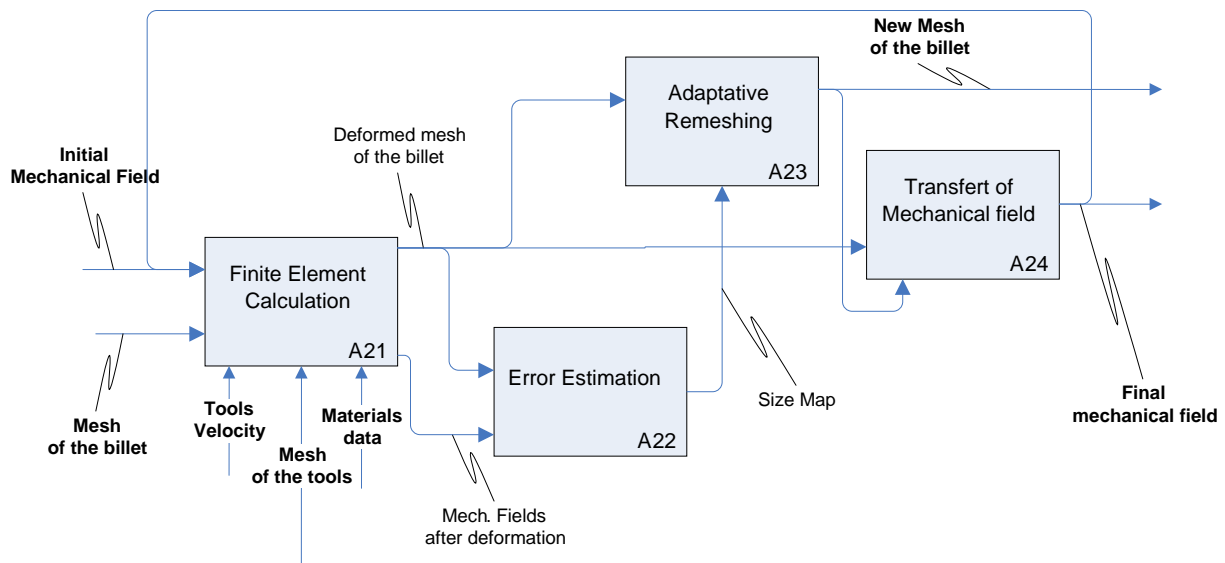


Figure 1. Simulation of forming process for a given geometry.

4 Bibliography

Nowadays there is lots of research concerning the optimisation of forming process because forming process tools become more and more reliable. The goal of the research is to provide engineers with a reliable tool allowing for accurate numerical simulation of the manufacturing process and prediction of the parts resistance. The optimisation of the part shape and process parameters has been carried out. Several parameters have an important role in the simulation of the process and can have an impact on the distribution of metal, the total energy and the cost.

In recent years research on forging optimisation has also been reported, in which objective functions are defined as the minimisation of forging energy [6], the residual stress field [7], the material damage [7] and the minimisation of the force undergone by the tools [8].

The optimisation variables can be chosen among the parameter having the most important impact on the forging process and being the most interesting from the designer point of view from his industrial background. Some of the frequently used optimisation parameters are the shape of the performing tools [6], geometry of the tools [7], the material [7], [8] and the temperature [9].

In the field of metal forming applications, the computational time of simulation is very high, ranging from few hours for the simplest problem to few days for the complex ones. Therefore the optimisation issue should be solved within a limited number of simulations; maximum 2 or 3 variables are generally used in simulation [8].

To develop the forging process optimisation system several numerical tools are required: geometric modelling [10], FE analysis [11], and optimisation computation [12]. Forge2 and Forge3 are frequently used to simulate the forging process and coupled with an optimisation

algorithm [6], ABAQUS is also used in simulation [8]. Currently there are no packages with both simulation and optimisation capabilities that can be feasibly used for the forging of complex shapes.

In this paper numerical simulations of metal forming processes are realized by using the finite element package developed in LASMIS and presented in the second paragraph. A package of optimisation algorithms BFGS, Quasi Newton and Evolutionary Algorithm has been developed in the LASMIS and will be coupled with the solver ABAQUS in future works.

5 Process optimization

The goal of the optimisation of the forming process is to bring a support for the companies to economise money taking into account satisfying the specifications. Most of time, specialists have some liberties to obtain their desired forged pieces. These methods of optimization rest on the following idea: to transform the problem of optimal design into a problem of minimization. To define this process we have to indicate: the material, the tools geometry, the initial piece geometry and the process parameters.

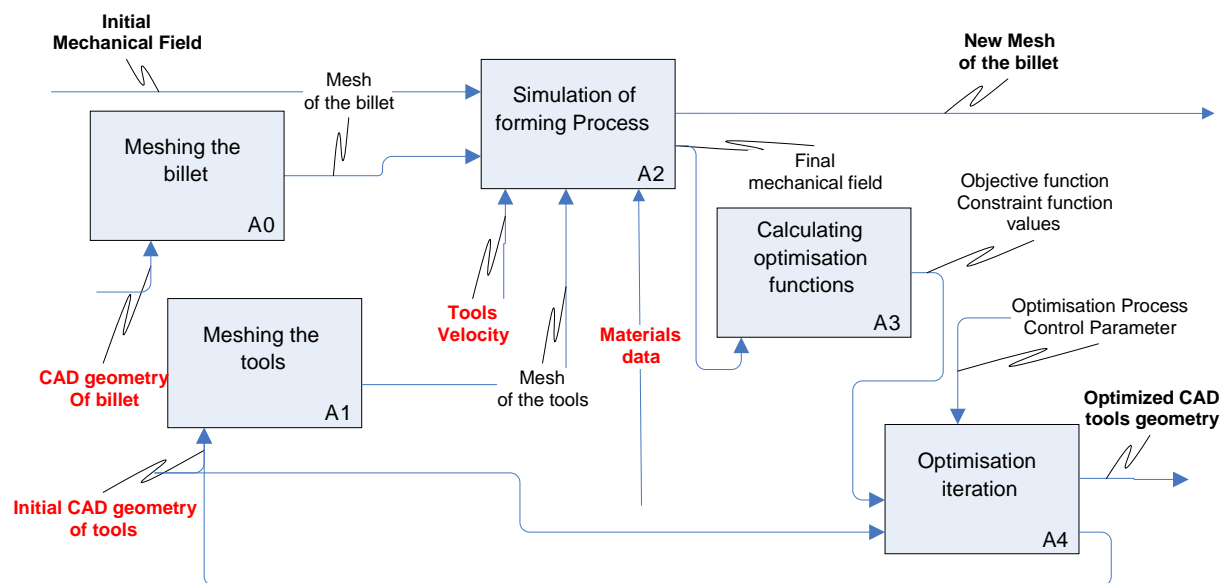


Figure 2. Overview of the optimisation process.

The numerical simulation then gives a qualitative analysis: deformations, forces necessary, appearance of defects, etc. From these results we could define the criteria of optimization. If the process is not satisfactory (if one of the criteria of optimization is not respected), we modify the process by changing the values of certain parameters of entry. In order to optimise the final piece geometry numerical simulations of metal forming processes are realized by using some specific simulation tools. LASMIS has developed a finite element package, allowing solving elastoplasticity problems with ductile damage in large deformation.

For each forming process many formability problems exist which usually are associated. The SADT activity chart presented on figure 2 highlights the input, the output and the control parameters of the forming process simulation in each step, the input parameters coloured in red could be served as optimization parameters for the forming process.

Specific type of billet is generally used in forging industry to obtain the rough forged, for example square billet, rectangular billet, tube shell, thin-shelled billet, dummy billet. A geometric parameter of optimisation could be the geometry of the billet. Concerning the type of material it is complex to take it as an optimisation parameter because it's generally imposed by the designer. Velocity in forming process has no an important effect on the forming process. This velocity has a limited value in reality. Finally the geometry of the tools is the most interesting to study because blacksmith make lots of errors in choosing the form of the tool. Relative to blacksmith the velocity of the tools is less important then its form which means the form of the rough forged.

In this article work is concentrated on the optimisation of the geometry of the tools. Several geometric parameters have an important role in the simulation of the process due to the complex form of the tools that for there is interest in doing lots of simulation in the metal forming in order to reduce the use of the experimental investigation and tests required in a real tryout process. The tools in LASMIS are able to evaluate the material damage and forging energy and take in constraint the shear stress. In process we notice the presence of residual material called bur that should be imperatively eliminated at the end of forging by machining. There is also interest to decelerate the fretting wear by minimizing the energy caused by the fretting between the tools and the piece what implies minimizing the wear of the tool, process simulation is used to predict defects and failures and material damage. For some massive pieces it's economically better to bore the pieces by punching [2]. These operations should imperatively ensure a gain of profits of productivity in comparison with operations of classic machining (form milling, drilling) thus it does only remain to carry out the final operation. In this paragraph, we will simulate an operation of forging that will be followed by an operation of deburring of a massive wheel in 2D. The wheel is obtained by hot forging. The function of the strain hardening is isotropic and isotherm. And we consider an elastoplastic characteristic with the following hardening law:

$$\sigma_s = \frac{Q}{b} \cdot \left(1 - e^{-b \cdot \bar{\varepsilon}^p}\right) + \sigma_y \quad (1)$$

Where σ_y is the limit elastic stress

$\bar{\varepsilon}^p$ is the equivalent plastic strain.

By changing the position of the burr "B" to characterize the quality of the billet, we use two objectives functions that consider a comparison between the maximum equivalent plastic strain and the homogenisation of the equivalent plastic strain for each simulated part. The formulas of the homogenisation of maximum equivalent plastic strain "f₁" and the equivalent plastic strain "f₂" are the followed:

$$f_1 = \max(\bar{\varepsilon}_i^p) \quad (2)$$

$$f_2 = \frac{1}{N} \cdot \sum_{i=1}^N (\bar{\varepsilon}_i^p - \bar{\varepsilon}_{moy}^p)^2 \quad (3)$$

Where N=number of knots in the meshed part.

$\bar{\varepsilon}_i^p$: is the equivalent plastic strain in knot number i.

$\bar{\varepsilon}_{moy}^p$: is the mean equivalent plastic strain for all knots of the meshed part.

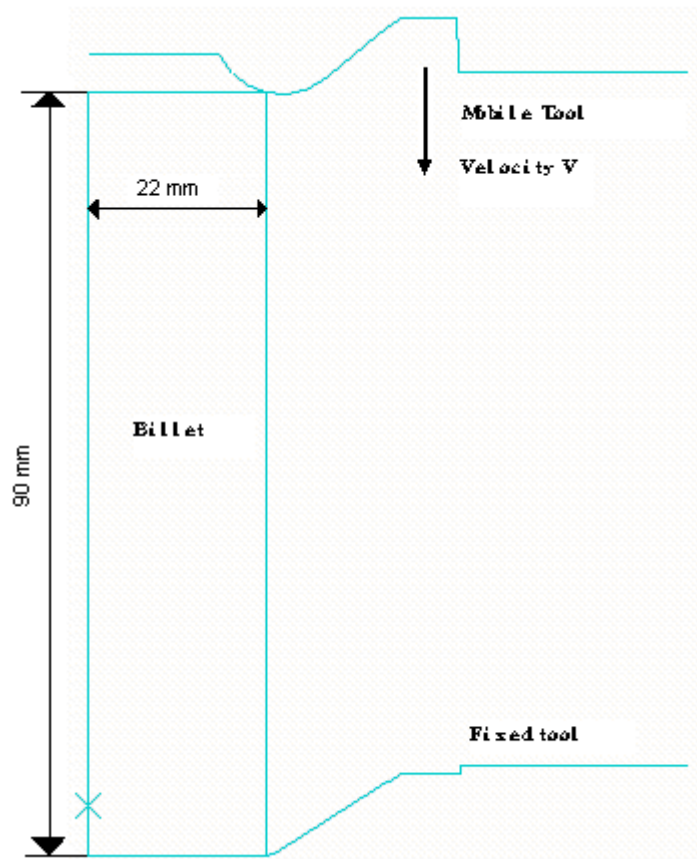


Figure 5. Tool and Billet geometric form.

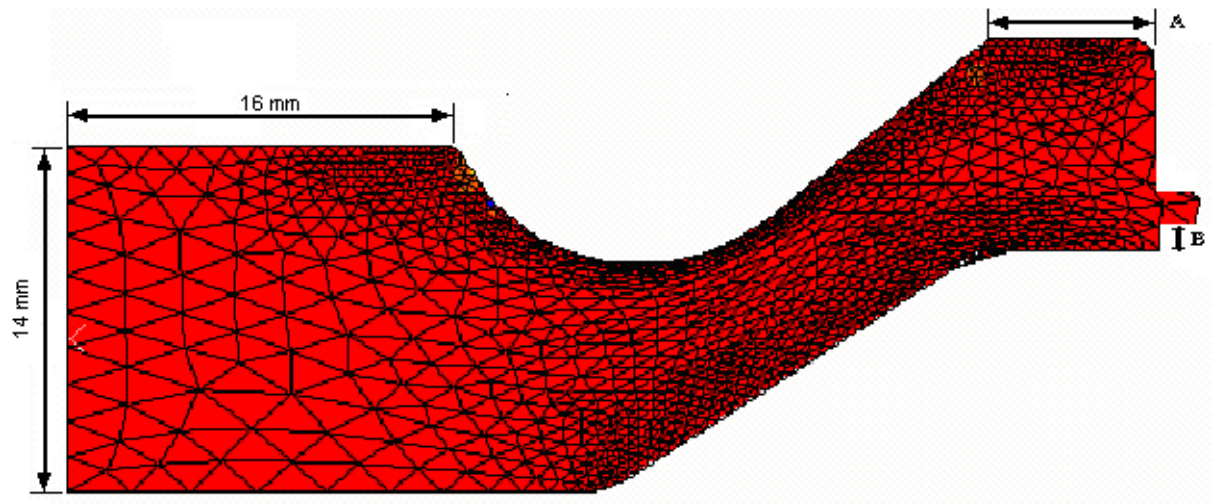


Figure 5. End of one simulation, deformed mesh

B	position 1	position 2	position 3	position 4	position 5
f_2	0.031147	0.031254	0.030287	0.03094	0.030239
B	position 6	position 7	position 8	position 9	position 10
f_2	0.029999	0.029745	0.030013	0.029715	0.029375

Table 1. Value of " f_2 " for different position of the burr

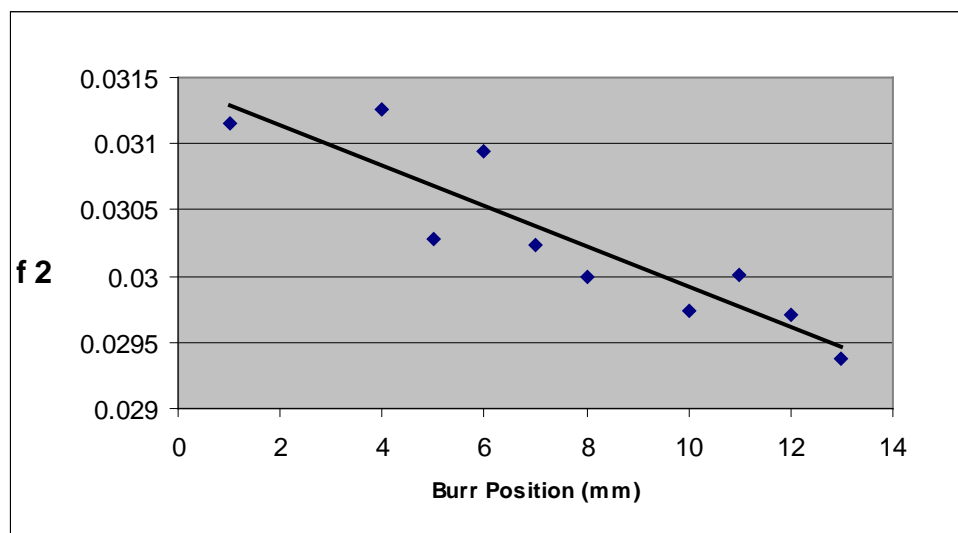


Figure 6. Different positions of the burr versus the homogenisation equivalent plastic strain

To notice that:

$$\left(\frac{f_{2\max} - f_{2\min}}{f_{2\min}} \right) \approx 9\%$$

In Table 1 position 1 correspond to B=0 and position 10 correspond to B=6mm.

Figure 6 presents the value of the homogenisation of elastoplastic deformation “ f_2 ”. For a range of variation of 6mm of the burr position, a reduction of 9% on the homogenisation of elastoplastic is occurred deformation “ f ”. It could be obvious that if by changing the position of the burr “ f_2 ” decreases but in other hand there is a limit for the position of the burr where “ f_2 ” reach its minimum the work in the future will be to develop a step of forming integration coupled with an optimization procedure in order to obtain the optimal parameters of the process.

B	position 1	position 2	position 3	position 4	position 5	position 6	position 7
f_2 for A=7mm	0.030287	0.030239	0.029999	0.029745	0.030013	0.029715	0.029375
f_2 for A=6.5mm	0.032083	0.032702	0.031212	0.031616	0.030571	0.030188	0.031663

Table 2. Value of “ f_2 ” for different position of “A” and “B”

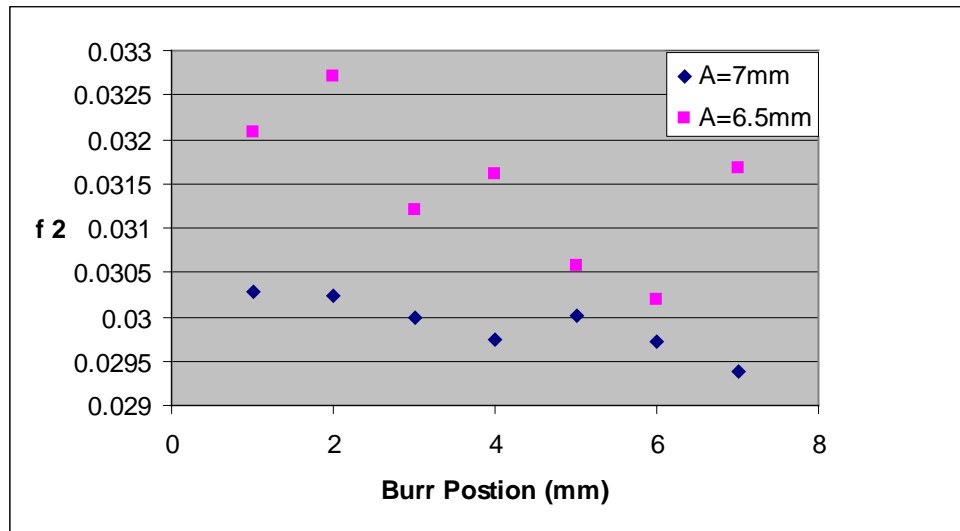


Figure 7. Different positions of the burr versus the homogenisation equivalent plastic strain “ f_2 ”

B	Position 1	Position 2	Position 3	Position 4
f_1 for A=7mm	0.94165	0.9224	0.9387	0.92029
f_1 for A=6.5mm	0.94872	0.92527	0.94632	0.92612

Table 3. Value of “ f_1 ” for different position of “A” and “B”

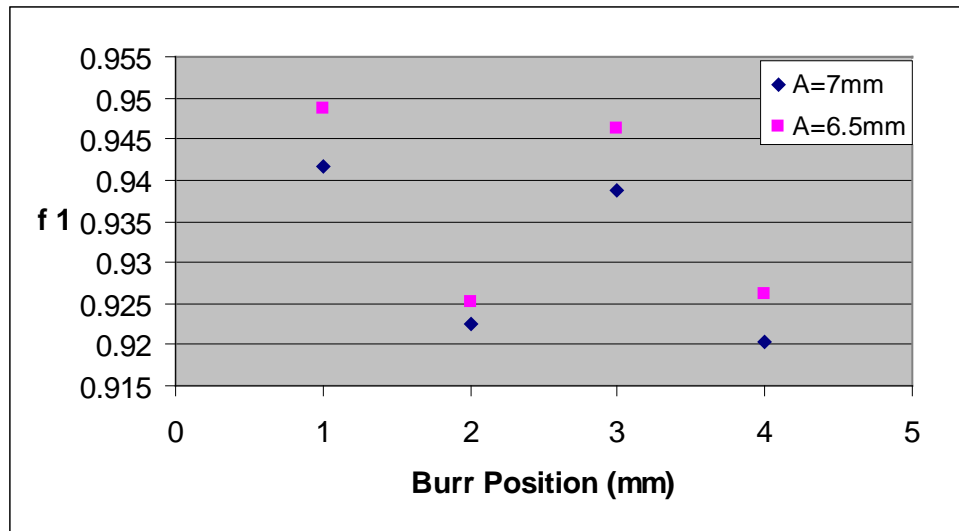


Figure 8. Different positions of the burr versus the maximum equivalent plastic strain “ f_1 ”

Another parameter has been taken into account, is the thickness of the external part “A”. Figures 7 and 8 show that for a decrease of 4% on “A”, an augmentation of 5% on the maximum equivalent plastic strain is occurred but only an increase of 1% of the homogenisation equivalent plastic strain is occurred. The set 1 of point in blue represent the homogenisation equivalent plastic strain for the higher dimension of “A” for 4 different positions of the burr the other set in pink represent the other set.

6 Conclusion

In hot forging process, it is important to find the conditions of manufacturing a product with good precision and quality. In this study, experiment and simulation for the hot forging process have been done by varying some geometric parameters. From the above discussion it has been shown various possibilities that:

An elevation of the burr position “B” leads to an increase in the homogenisation of equivalent plastic strain “ f_2 ”.

for a fixed position of the burr “B”, the higher values of the maximum equivalent plastic strain “ f_1 ” and the homogenisation of the equivalent plastic strain “ f_2 ” correspond to the lower distance “A”.

This usage has given ideas and guidelines on how geometric form could have an influence on the forming process. One of our principal objectives in the future is to develop a step of forming integration coupled with an optimization procedure in order to obtain the optimal parameters of the process.

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