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Expert system for hot forging design

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Abstract

Planning hot forging processes is a time-consuming activity with high costs involved because of the trial-and-error iterative methods used to design dies and to choose equipment and process conditions. Some processes demand many months to produce forged parts with controlled shapes, dimensions and microstructure. This paper shows how expert systems can help engineers to reduce the time needed to design precision forged parts and dies from machined parts. The software ADHFD interfacing MS Visual Basic v.5.0 and SolidEdge v.3.0 was used to design flashless hot forged gears, chosen from families of gears.

Keywords: Expert system; Hot forging; Die design

1. Introduction

In recent years, hot forging has shown continuous technological changes, mainly in the geometry of the dies and in the dimensional accuracy of forgings. Since hot forging have to be competitive even for small lot sizes, forgings weight and machining allowances are being reduced and therefore subsequent machining is being reduced with low final costs and investments. With hot precision forging and the concept of near-net-shape-manufacturing (NNS), costs with machining are drastically reduced, so forging operations (and their planning) became an important part of the final cost [1,2].

Most of the time (and costs) involved in planning hot forging processes is related to activities strongly dependent on human expertise, intuition and creativity [3] and also to iterative procedures involving extensive experimental work. In order to minimize this lead time, related expert knowledge and criteria must be transferred to automated knowledge-based and rules-based systems.

Tisza [4] states that there are a small number of expert systems applied in metal forming, when compared with other manufacturing fields. The numerous variables involved in metal forming processes make difficult the automation of decision making and planning of these processes, but some examples can be found particularly for multi-stage processes like cold forging and deep drawing [3–7] and for hot forging [8,9].

Biswas and Knight [10] point out that the rationalization and automation of the procedures by expert systems bring benefits to the hot forging industry like rationalized tooling, improved factory layouts, systematic design procedures, improved estimating and costing procedures, and standardized work planning and process design.

2. Planning precision hot forging processes

Precision hot forging shows some advantages when compared to conventional hot forging: it minimizes subsequent machining, improves forgings quality avoiding overlaps and internal defects, reduces forging loads, and can eliminate heat treatment, since internal stresses are reduced. To achieve these characteristics, process variables like forging temperature and billet volume must be precisely controlled [11].

The planning of a new hot forging process can be divided into three groups of procedures, as shown in Fig. 1. In group A the machined part is modified:

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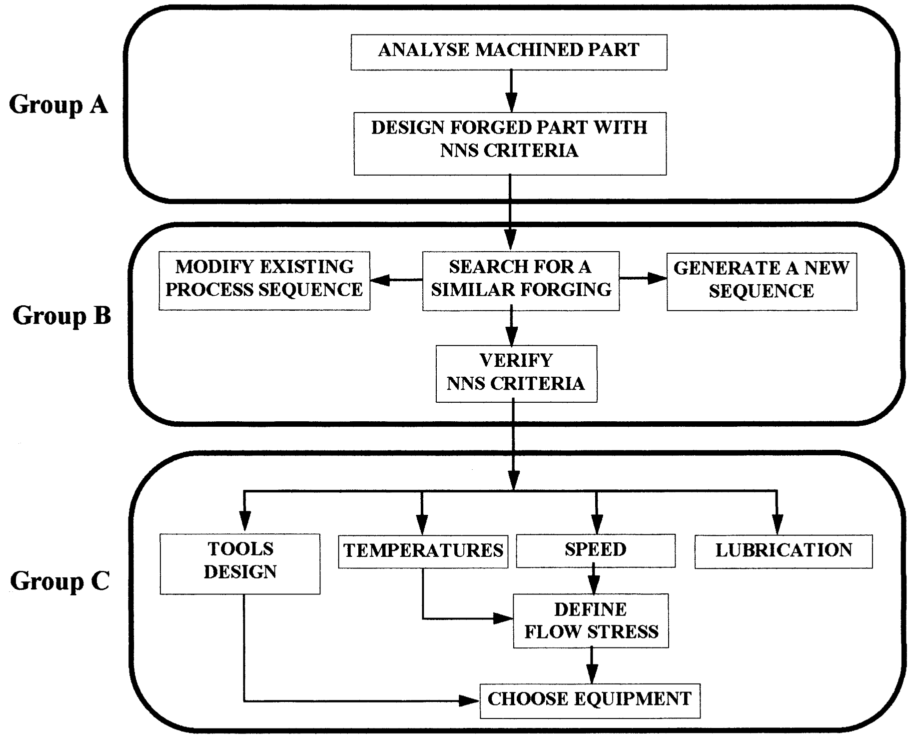


Fig. 1. Stages for hot forging planning.

machining allowances are applied where necessary, a parting line is properly chosen, appropriate radii are applied to fillet and corners, internal and external drafts are added, holes, ribs and webs are designed to keep forging dies undeformed. The forged part is finally designed considering NNS criteria.

The process sequence is designed in group B. Considering part characteristics (material, size and geometry), lot size and available equipment, it is possible to define the number of operations and to design the preform. Using the principles of group technology and defining families of parts, it is possible to find similar forgings and adopt an existing sequence or modify it to the new design.

The most difficult and costly stage to plan each operation is to determine the correct preform geometry to assure complete filling of the dies. In industry this stage is still based on 'trial-and-error' iterative procedures to the production of 'good parts', after successive measurements of the forgings and corrections in dies geometry. In recent years, many works based upon numerical methods like the finite element method (FEM) show that computerized analysis can help the forming industry to define the best process sequence, reducing time and costs involved [2,12,13].

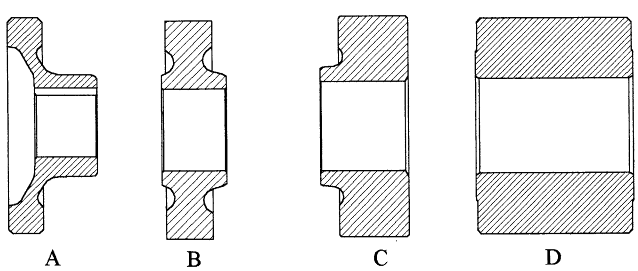


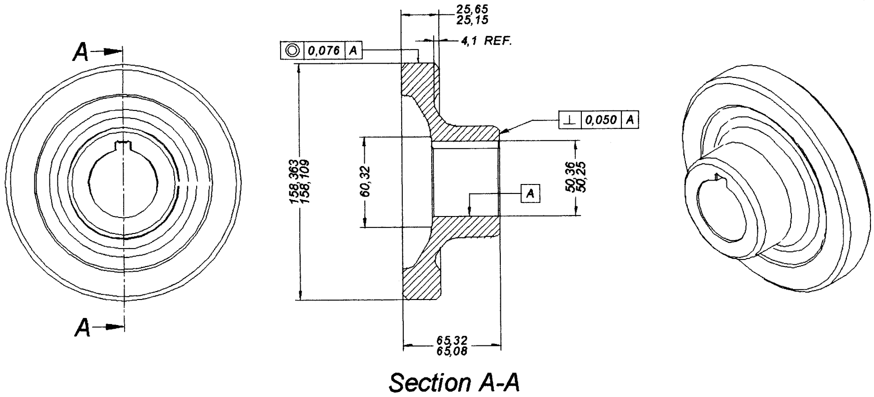
Fig. 2. Families of automotive gears.

Once the process sequence is defined, other process parameters are chosen in group C: forging temperatures, lubricants, and equipment. The dies are designed considering preforms geometry, thermal expansion, and the use of standardized tools and inserts.

3. The ADHFD system

This work shows a semi-automatic system developed to design dies and plan precision hot forging using near-net-shape criteria. The ADHFD (automated design of hot forging dies) is being developed to work with families of automotive gears (longitudinal sections shown in Fig. 2), classified by designs: with or without web, one-sided or two-sided hub, and by characteristic dimensions (external diameter, hub diameter, rim length, hub length). These gears are forged within some near-net-shape principles: small machining allowances, flashless, minimal draft angles and fillet radii [14].

The expert system ADHFD is being developed with four codes. The rule-based system is written in MS Visual Basic v.5.0 and linked to MS Access v.7.0 data-



Gear specifications:
- material: SAE 8620 steel
- number of teeth: 34
- helix angle: 37.5°
- ball diameter: 7.42
- dimension over balls: 162.53 / 162,37

Fig. 3. Automotive gear.

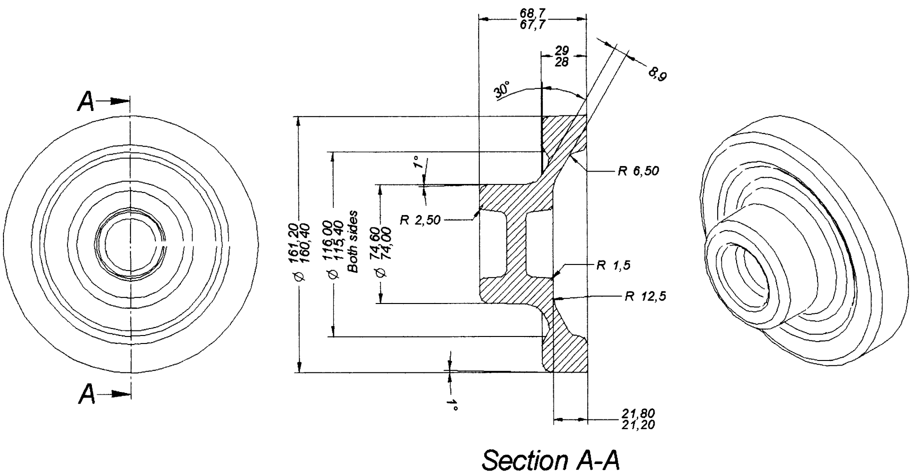


Fig. 4. Gear forging.

bases. Metal flow is simulated with Ansys v.5.3 to prevent filling defects and to optimize process sequence. With SolidEdge v.3.0 the forgings and the dies are modeled in 3-D and assembled. The volumes are then calculated and respective technical drawings generated.

The system is considered semi-automatic since the user can choose similar forgings, analyse machined part details and decide how to modify the forging and the process sequence.

The databases contain detailed information about variables of processes already planned: raw materials properties (stock size and tolerances, flow stress, formability), forging temperatures, lubricants, presses (capacity, table dimensions, stroke and speed), about NNS criteria and about typical process sequences (billet cut-off, heating, preform, finish forging and trimming).

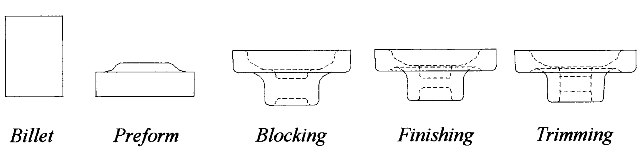


Fig. 5. Process sequence.

4. An example of application

The forging process of the gear shown in Fig. 3 was planned using the expert system developed. This gear is similar to the family A (Fig. 2) with web and one-sided hub. The teeth were previously removed since they will be cut by hobbing. In the first stage (group A—Fig. 1) after the analysis of the machined part, the machining allowance was defined equal to 2.0 mm, based on the biggest dimension (external diameter 158.36/158.11). This allowance was added to the surfaces with necessary subsequent machining (the hole, the external diameter, the faces of the hub and the faces of the rim). Then the fillet and corner radii were chosen. The 1° draft angle was defined to help removal of the forging from the die. The height and the wall thickness of the hub define the thickness of the internal web equal to 12.0 mm, large enough to prevent the damage of workpiece and dies. Finally, forging tolerances were defined to all dimensions. Fig. 4 shows the final forging.

In group B, after searching for a similar forging, it was chosen to modify an existing forming sequence with four operations: preforming, blocking, finishing and trimming (Fig. 5).

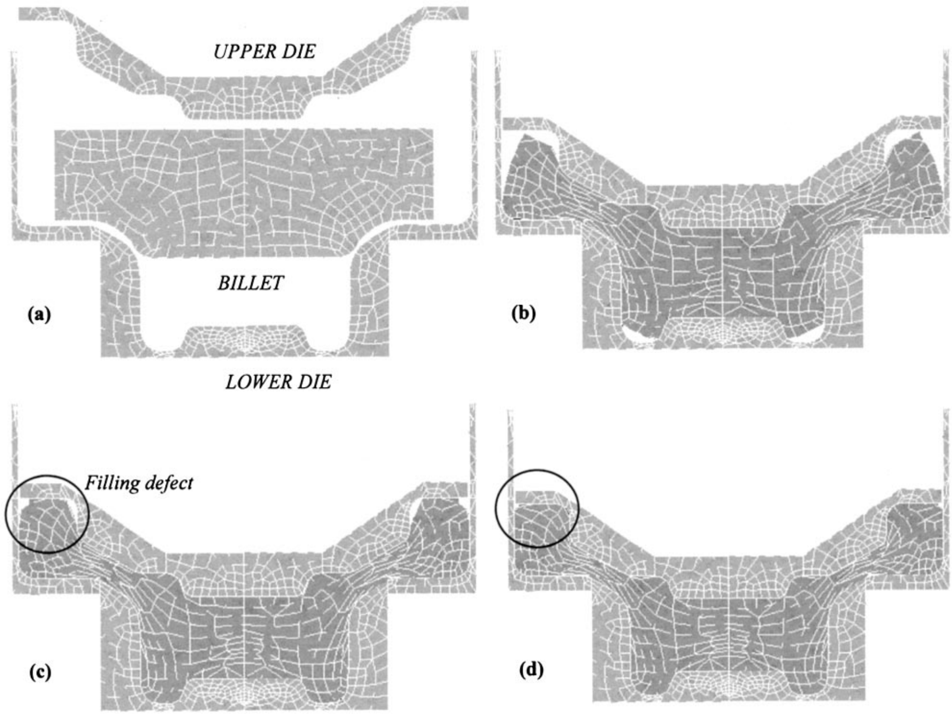


Fig. 6. Simulated evolution of the blocking operation.

The dimensions of the billet were calculated from the volume of the final forging. The best shape and dimensions of the preform were defined from the results of simulations with FEM program ANSYS. As shown in Fig. 6 an incorrect billet shape causes the incomplete filling of the dies in the blocking operation and internal defects in the forged part.

Finally (group C) the dies were designed considering the dimensions of the parts in each operation, added with 1% because of the thermal expansion verified at forging temperatures. Table 1 shows process parameters chosen from databases and related to material properties, the number of operations and the results of simulation.

Table 1
Process parameters

Billet dimensions	$\varnothing 25\times 35$ mm
Initial forging temperature	1100°C
Final forging temperature	950°C
Press	Eccentric forging press
Capacity	2000×10^4 N
Stroke	280 mm
Stroking rate	80 min^{-1}
Table dimensions	1090×1350 mm
Lubricant	Colloidal graphite in oil

5. Conclusions

The expert system ADHFD showed good performance when aiding the design of flashless hot forged gears. The design time is considerably reduced when compared with conventional techniques. Some modifications have to be done in the program to allow the design of asymmetric parts with complex geometric details.

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