LIST OF PAPERS

Forging Simulation at Izeltas

E. Arbak[1], S. Ünal[1], L. Boylu[1], İ. Erzincanlı[1], A. E. Tekkaya[2]

[1]Izeltas A.S., Isikkent, 35070, Izmir, Turkiye

[2]Institut für Umformtechnik und Leichtbau, Universität Dortmund, Germany and Manufacturing Engineering Department, ATILIM University, Ankara, Turkiye

Abstract
As a remarkable alternative to the trial-and-error procedure carried out on the shop floor following the tool manufacture, simulation on an interactive computer environment enables the tool designer to foresee potential defects on the part such as laps and under-fill and stresses on the tool. This paper summarizes the theoretical and initial verification work carried out at Izeltas with the specific goal of examining materials behavior under elevated temperature and high-stress conditions, studying the effect of temperature and strain rate on the flow characteristics, the effect of lubrication on tool friction and the effects of hammer working parameters on the material flow characteristics. Results of the mentioned work will enable the engineers to understand the mechanics of the process and to improve the tool design reducing the costly price of trial forging operations, short tool life and scrap material.

Keywords:
Forging, Simulation, Methodology

1 INTRODUCTION

Izeltas launched a project in February 2006 with the aim of acquiring a forging simulation tool, which would enable the process engineers to foresee potential defects existing in the nature of forging process such as laps and underfills, while providing an insight to the stresses generated inside the die tool during forming. In an environment, where previously, new part forging tests were carried out through trial and error with the expensive die tool already manufactured, the new simulation process introduced a variety of advantages and challenges.

Along with the time-saving and cost-cutting characteristics of the simulation process, the reliability and the accuracy of the results are often questioned by the engineers and decision makers, when the cost of tool making, rebuilding and inadequate quality is taken into account. No matter how user friendly the software is, the quality of the data logged in the simulation tool is of utmost importance and surely one thing that directly affects the output. Getting closer to reality with sound simulation results builds up confidence in the process and that is the time when companies start to realize the actual benefits. About 30% of the world-wide forging industry is using finite element simulations in order to [1]:

1. Optimize running products by cost and quality.
2. Develop new products in shorter time.
3. Increase forging process know-how and compansate for the gap of technological experience.
4. Assist training and marketing effectively.

This paper aims to provide an insight to the theoretical and experimental work carried out at Izeltas with the special emphasis on material flow behavior under elevated temperature and strain rate, the effect of lubrication on friction and kinematics of forging hammers.

2 THE PROJECT

Today, forging companies are facing international competition due to the globalization in manufacture. Especially, lower manufacturing costs introduced by China and India are putting pressure on the market, where companies are strongly pushed to take precautionary steps to confront the challenge. In such an environment, Engineering Department at Izeltas has taken a decision and started a project to select and integrate suitable simulation software into the existing forging die tool design process. The project has also received "Scientific and Technological Research Council of Turkey – TÜBİTAK's approval for funding.

First step was to carry out a benchmark process comprising four software suppliers, which are:

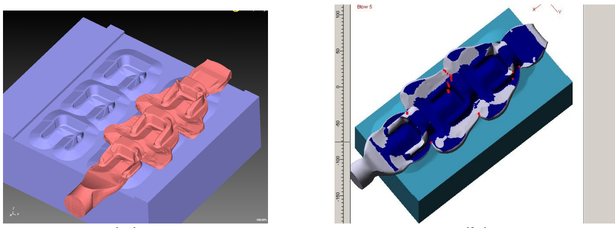
1. Quantor's Qform;
2. MSC's Superforge;
3. SFTC's Deform;
4. Transvalor's Forge3.

Same sample part die tool 3D model in IGES file format and related input data were sent to all suppliers, requiring them to simulate the forge and report on the result. The packages were compared on the basis of accuracy, user-friendliness, material database, visual properties, parallel processing and time required to solve the simulation.

The part selected for the benchmark process was a steering mechanism joint. In the real forging, the major defect was the formation of laps beneath the joint arms.

Figure 1. Forging Defects

Two of the simulation results received clearly showed the possible areas of lapping on the billet. There were also gaps in the arms due to inadequate lubrication conditions.

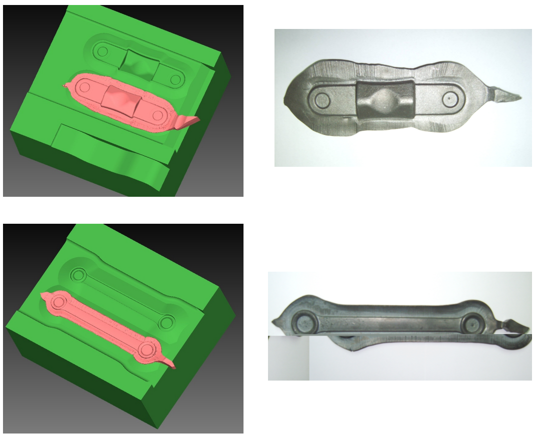


(a) (b)

Figure 2. Pictures of the Simulation Results

Figure 2 shows the output of the simulation, MSC's Superforge (a) and Quantor's Qform (b), where possible laps are denoted visually by red dots on the right. Also contacting surfaces are colored in dark blue, in contrast to grey areas, where gaps may eventually generate.
Having selected the suitable tool, MSC's Superforge, in accordance to the company specific requirements, next step was to install the software to a powerful PC configuration and start to verify the input data required for the tool to carry out the simulation. This input data can be classified in three major sub-groups:

1. material characteristics;
2. forging equipment properties;
3. friction parameters.



(a)

(b)

Figure 3. Actual and Simulation Forgings of a Joint (a) and a Ring Wrench (b)

First simulations, as in Figure 3, proved promising results, where, process engineers also appreciated the importance of friction parameters and material properties. In these two simulations, main body of the forging showed no deviation but dimensions of the flash differ from the real for the same equipment properties. .

3 INPUT DATA

In simulation tools, the quality of the input data determines the quality of the result. The input data should closely reflect the values of the real process.

3.1 Material Characteristics

MSC Superforge requires two essential groups of information on the material characteristics. One is the elastic, including thermal properties and the other is the plastic properties. Elastic constants include Young's modulus, Poisson's ratio and thermal properties, thermal conductivity and specific heat. On the plastic side, plasticity is defined by four material behavior models, two of which for cold forging and two for hot forging. At Izeltas, hot forging is the main forming process, therefore, we use;

$$\bar{\sigma} = \max\left(S, c\dot{\bar{\varepsilon}}^{m}\right) \tag{1}$$

where, $\bar{\sigma}$ is the effective stress, S is the minimum yield stress, $\dot{\bar{\varepsilon}}$ is the strain rate, c and m are the yield constant and strain rate exponential. We cannot apply the yield criteria at room temperature as forging at elevated temprerature such as 1000°C makes strain rate a crucial player in the deformation mechanics.
Strain rate, $\dot{\bar{\varepsilon}}$, is formulated as:

$$\dot{\bar{\varepsilon}} = \frac{d\bar{\varepsilon}}{dt} = \frac{dh}{h \cdot dt} = \frac{v_w}{h} \tag{2}$$

$\bar{\varepsilon}$ is the strain, h is the specimen height and v_w is the deforming speed.

Yield Stress
Yield stress is dependent on strain, strain rate, temperature and material. Yield stress curves are drawn at constant strain rate and temperature. In Figure 1, it can be observed that the forming strength of the material at 900C and between forming speeds of 1,5 to 8 s^{-1} is 2,5 to 3 times greater than the strength at 1200°C [2].

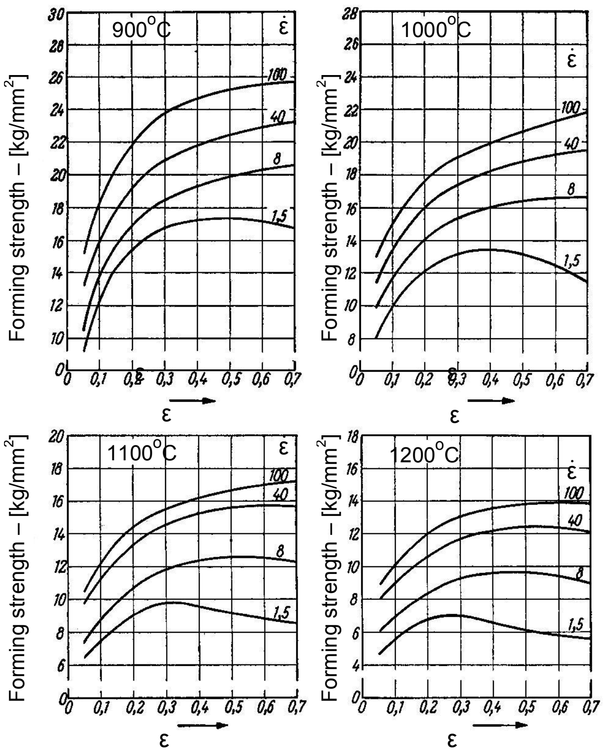


Figure 4: Forming Strength of Carbon Steel C15

In hammers forming work can be calculated with the drop height and ram weight, while taking account of energy consumed by ram re-bounce and body deformation. This total energy lost is assumed to be 2% at most

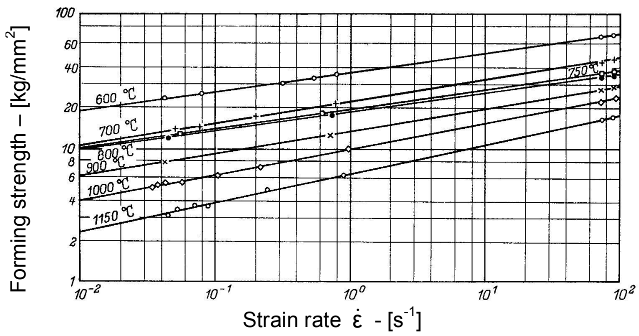


Figure 5. Relation between forming strength and speed

In Figure 2, it can be summarized that rising temperature decreases the strength; however, with the increase in speed, it gets harder to deform the material. Lange and Meyer [3] state that the relation between strength and speed can be given as (for constant strain and temperature):

$$\sigma_1 = \sigma_2 \left(\frac{\dot{\varepsilon}_1}{\dot{\varepsilon}_2} \right)^m \tag{3}$$

where, m is the hardening exponential.

3.2. Forging Equipment Properties

At Izeltas we utilize forging hammers, which are powered by hydraulics, pneumatics or gravity. In general, kinematic energy of any type of hammer is given as:

$$E_0 = \frac{m_r V_0^{\ 2}}{2} \tag{4}$$

where, m_r is the mass of the ram and V_0 is the velocity of the ram at the time of contact. On the other hand, velocities of the ram for drop and pressurized – hydraulic or pneumatic – hammers are formulated according to the acceleration. Drop hammers are characterized by the acceleration of gravity (g) whereas, pressurized hammers by the acceleration of the ram.

Drop hammers: $V_r = \sqrt{2gz}$ (5)

Pressurized hammer: $V_r = \sqrt{2az}$ (6)

where, a is the acceleration and z is the vertical drop height of the ram.

Tool speed is given by the manufacturer for various hammer types and it is the top speed at the time of contact with the billet. In hydraulic hammers it is provided as 5 m/s and for our hammers it is 5 to 6 m/s.
In potential energy terms, Following applies:

Drop hammers: $E_0 = m_r g z$ (7)

Pressurized hammers: $E_0 = (m_r g + p_c A_c) z$ (8)

where, p_c and A_c are pressure in the cylinder and cross-sectional area of the piston.

3.3 Friction Parameters

In MSC SuperForge forging simulation, we use friction shear factor (m) rather than the friction coefficient (μ). Coulomb law describes the friction with regard to normal stress (σ_n) as:

$$\tau_s = \mu \sigma_n \tag{9}$$

Tresca's friction model defines the friction shear factor as:

$$\tau_s = m \sigma_f / \sqrt{3} \tag{10}$$

where, σ_f is the yield stress of the material.

A value of 1 for m denotes that the material sticks on the surface, whereas 0 describes the perfect slip. For the calculation of m values for our specific dies (1.2714) and billets (C15 and Cf53), process engineers carried out ring compression test using a hydraulic hammer and a flat die, with and without lubrication. The lubrication element is a graphite and oil mixture.

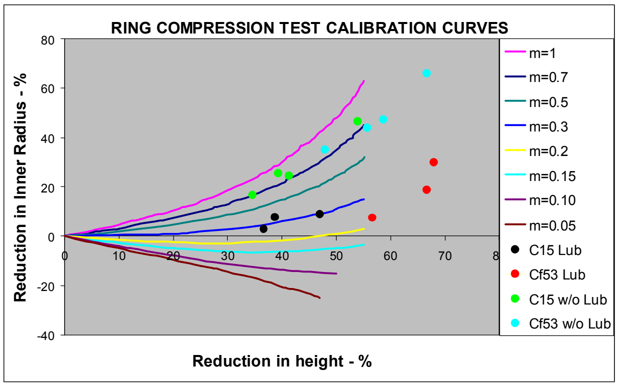


Figure 6. Ring Compression Test Calibration Curves

In Figure 6, unlubricated C15 (green dots) and Cf53 (turquoise dots) results in a friction shear factor, m, of around 0,7. On the other hand, when lubricated, m value drops down to 0,3 for the same material (dark blue and red dots, respectively) and surface properties.

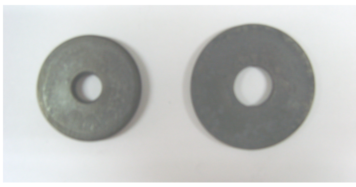


Figure 7. Unlubricated and Lubricated Cf53 Samples

Physical dimensions of the unlubricated C15 forged in real and simulation are provided in Table 1;

	Height	Outer ∅	Inner ∅
Real	6,9 mm	59,7 mm	12,0 mm
Simulation	6,3 mm	61,2 mm	10,8 mm

Table 1. Forged Ring Dimensions

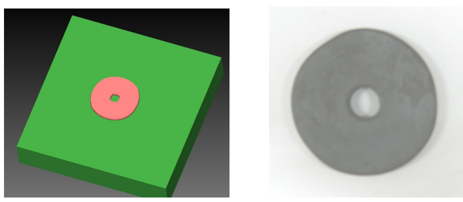


Figure 8. Ring Compression of C15 in Real and Simulation

4 SUMMARY

This paper summarizes the project undertaken at Izeltas for the integration of a forging simulation tool to the forging die-tool design process. The reality of the simulation result highly relies on the quality of the input data. Therefore, verification work at the beginning of such integration projects is of great importance in order to obtain clear solutions, not just visually perfect but also close to real life outputs. No matter how good the user interface is, users should not take the tool and what it offers for granted but try to involve in finite element analysis, plasticity theory and material science.

5 REFERENCES

[1] Tekkaya, A.E., 2003, Process Simulation in Forging: A Report from the ICFG Subgroup on Simulation, Proceedings of ICFG/NACFG International Cold Forging Conference, Ohio/USA.

[2] Meyer, H., 1958, Zahlenwerte über die Unformfestigkeit von Unlegierten Stählen nach neueren Schrifttumsangaben, Schmiedetechnische Mitteilungen, 12/6, 673,676.

[3] Lange, K., Meyer, H., 1977, Gesenkschmieden, Springer-Verlag, Berlin, 16-18.