Complementary Aspects in Physical Simulation of Hot Forging Operations

Bariani, P.F., Berti, G., D'Angelo, L. and Guggia, R.
DIMEG, University of Padua, Padova, Italy

Summary

The paper presents some recent applications at the DIMEG lab of physical simulation techniques aimed at analysing and modelling hot forging operations. The applications concern (i) monitoring of force-and-moment history over the forging cycle of complex parts, (ii) replicating on samples local thermal/mechanical profiles that are predicted by FE codes and (iii) measuring interface parameters such as heat transfer coefficients and temperature at the die surface.

1. Introduction

Depending on the objectives of simulation and phenomena to be analysed, two complementary approaches are generally used in physical simulation of forging operations. The first consists of simulating, according to specific scope and objectives, a production unit process with real materials on a laboratory scale and monitoring or controlling the important process parameters [1, 2]. The product resulting from such laboratory simulative tests can be mainly analysed in terms of material characteristics. The second approach to physical modelling is to devise laboratory tests that are faster, easier and less expensive than a sub-scale production process. Model materials and visioplasticity techniques [3] are utilised in this approach, especially for analysing flow behaviour.

The paper presents some applications of experimental facilities at the DIMEG lab for the simulation of bulk metal forming operations such as hot forging of crane links, turbine blades and chain rollers. The presentation focuses on the most original aspects such as (i) monitoring the history of the force and moment components applied to the dies, (ii) replication, under computer control, of local thermal/mechanical profiles that are predicted by FE codes and (iii) evaluation of interface parameters such as heat transfer coefficients and temperature at the die surface.

2. Physical Simulation Equipment

New experimental facilities have been recently developed and installed at the DIMEG lab. They are specifically designed for physical simulation experiments both on real and model materials, according to the two above mentioned approaches. The two main facilities include:

(i) a 2000 kN lab press (named *Toy Press*) equipped with a multi-axes force-and-moment transducer. The transducer consists of a 3-plate die-set with three piezo-electric 3-axes load cells connected to a Pc-based acquisition system that provides, over the forming cycle, the history of the three components of force and moment as well as the attitude of the resultant of the forming forces. Main utilisation of the *Toy Press* concerns forging experiments with model materials (lead and plasticine) aimed at monitoring the die loading system history, analysing material flow defects in cavity filling and the effect of process parameters such as billet geometry, preforms, parting line location and flash design [4].

(ii) a multi-purpose dynamic thermal/mechanical simulator Gleeble 2000 system with Hydrawedge®, capable of multi-stage forging and heat-treatment experiments where controlled parameters are strain, strain rate, temperature and force. The heating device and temperature control permits heating rates of the specimen up to 20,000 °C/s, depending on the size of the specimen. Maximum load and stroke rate are 200 kN and 2 m/s respectively. Thanks to these performances, the system is mainly utilised in material (rheology and workability) and interface (friction and heat transfer) data acquisition, as well as in replicating dynamically on test samples the thermal and mechanical cycles occurring during the real process.

3. Application Examples

3.1. Force and Moment History in Crane-Link Forging

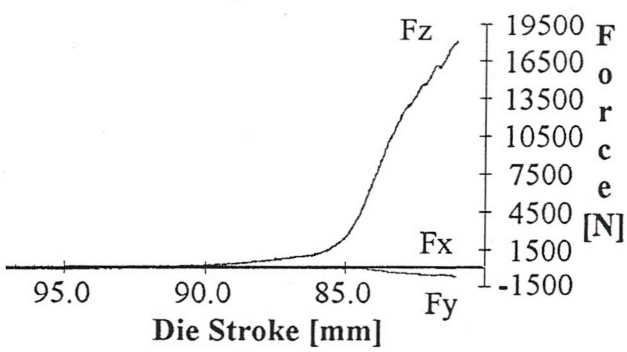

Fig. 1 *History of 3 force components*

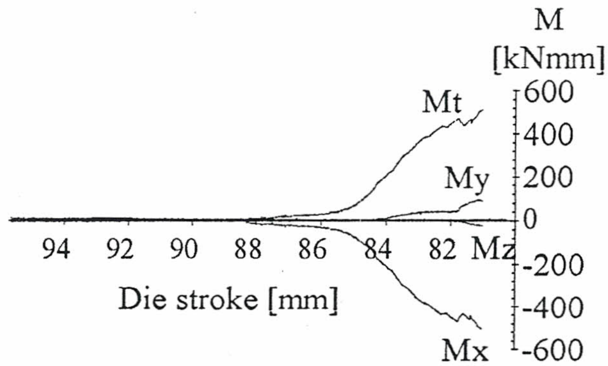

Fig. 2 *History of 3 moment components*

Main difficulties in hot forging of a new-design large crane-link for earth-moving machines concerned flash production, too high forging forces compared to the press loading capacity and die matching errors due to the side thrusts induced by the irregular parting line.

The forging operations at the different steps of the forging process have been simulated on the *Toy Press*, the model material being plasticine [5]. The history of the three force (**Figure 1**) and moment (**Figure 2**) components have been analysed together with the continuous change of magnitude and attitude (**Figure 3**) of the resultant forging force over the forging cycle.

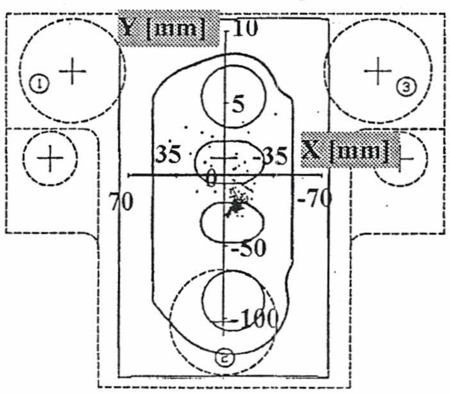

Fig. 3 *Application point of resultant force*

3.2. Replication of Local Thermal/Mechanical Profiles in Turbine Blade Forging

Tests on the Gleeble system replicating on TiAl6V4 cylindrical specimens the thermal and mechanical events occurring during the hot multi-step forging of gas turbine blades have been run with the aim of investigating the effect of temperature and strain rate on the flow stress in a dynamic multi-hit deformation process. Most of the tests focused on the evaluation of the material response to deformation procedures where small amount of deformation per step (0.15-0.30) is performed at strain rates in the range of 1-4 s^{-1}. The strain rate and the strain increments per step are accurately reproduced under the control of the Hydrawedge ® servo system installed on the Gleeble. During the deformation stages, the temperature and the strain are kept uniform in the whole specimen thanks to multi-layered (Tantalum and graphite) film used as interface between specimen and anvils [6].

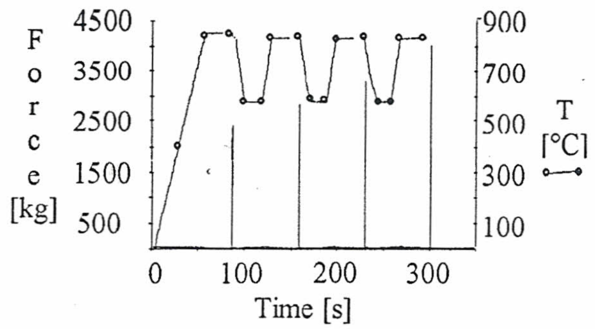

Fig. 4 Temperature and force history in a 4-step forging process

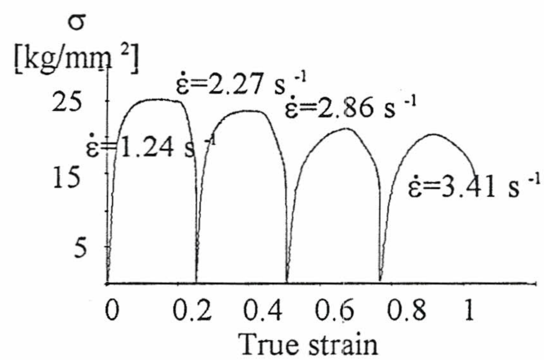

Fig. 5 True stress - true strain curves associated to the four steps

Temperature and force history in a 4-step forging process are shown in **Figure 4**. Stress-strain curves at the different strain rates associated to the four steps are shown in **Figure 5**.

3.3. Temperature History of Die-Inserts in Chain-Roller Forging

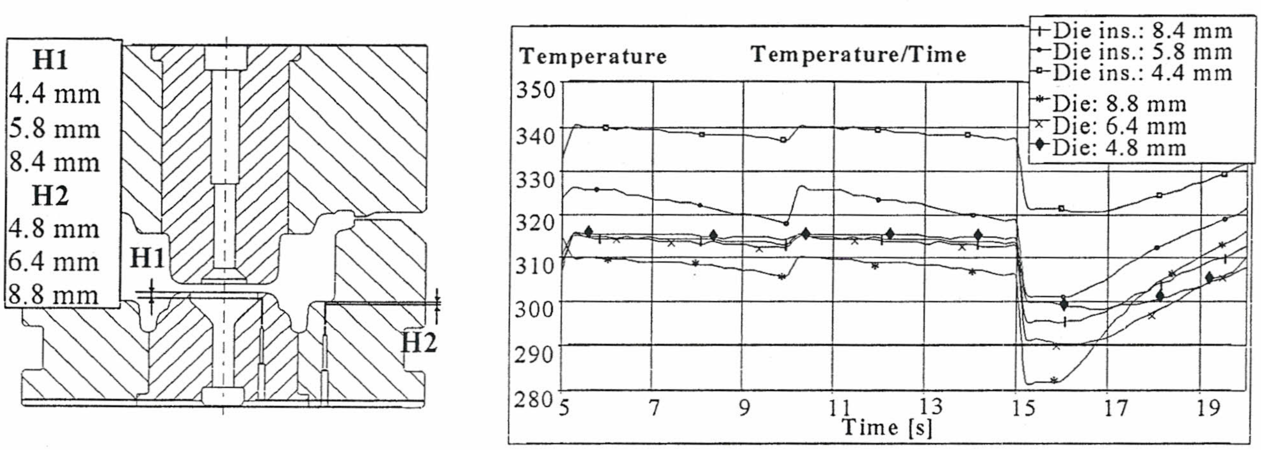

Fig. 6 Location of thermocouples in the lower die (left) and temperature measurement in the lower die during the real process (right)

In a project aimed at investigating wear of die inserts in hot forging of chain rollers and comparing different combinations of coating- and base-materials for dies, temperature gradients and history at the surface layers of the inserts had to be evaluated during the whole forging cycle. The temperatures have been reconstructed through FEM simulations based both on measurements from thermocouples embedded into the real dies (**Figure 6**) and values of the heat transfer coefficient measured for the different interface conditions occurring over the cycle, including the spraying of the lubricant.

Heat transfer coefficient has been measured both in compression tests of cylindrical specimens between flat punches and in plane strain tests run on the Gleeble system with contact conditions reproducing, as much as possible, those predicted by FEM simulations [7]. The evaluation procedure is based on an inverse analysis technique where numerical results from FEM simulation of the two tests are compared with and fitted to experimental results from the tests. **Figure 7** shows a comparison between numerical and experimental temperatures in plane strain test.

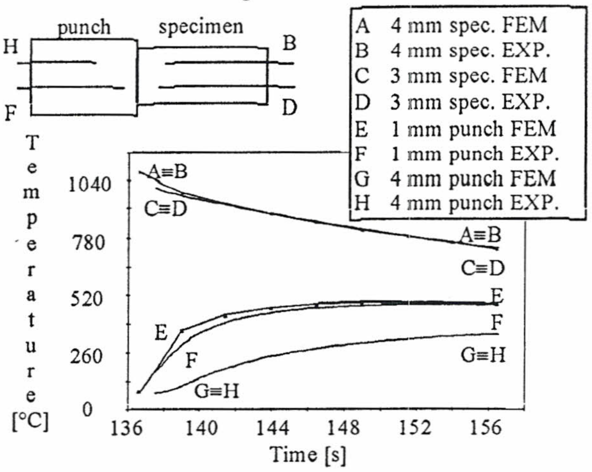

Fig. 7 Comparison between numerical and experimental temperatures in plane strain test

4. Conclusions.

Recent applications at the DIMEG lab of physical simulation techniques to the analysis and modelling of hot forging operations have been presented. They include: (i) monitoring of force-and-moment history over the forging cycle of complex parts, (ii) replicating on samples, under computer control, local thermal/ mechanical profiles and (iii) evaluation of interface parameters. The three applications make evident the complementary aspects of the two main lines of simulation, the numerical and the physical one, as well as of the two approaches in the physical simulation.

References

[1] Altan, T. and Lahoti, G.D, Limitations, Applicability and Usefulness of Different Methods in Analysing Forming Problems, Trans. of ASME, May 1970.

[2] Ferguson, H.F., Fundamentals of Physical Simulation, DELFT Symposium, December 1992.

[3] Wanheim, T., Physical Modelling of Metalprocessing, Procesteknisk Institut, Laboratoriet for Mekaniske Materialeprocesser, Danmarks Teknisk Højskole, Denmark, 1988.

[4] Bariani, P.F., Berti, G., D'Angelo, L., et al. Some Progress in Physical Simulation of Forging Operations, II AITEM Nat.l Conf., Padova, September 1995.

[5] Bariani, P.F., Berti, G. and Meneghello, R., Monitoring the Force-and-Moment History in Forging Complex Parts, DIMEG Internal Report (in Italian), March 1996.

[6] Bariani, P.F., Berti, G., D'Angelo, L. and Guggia, R., Investigation on the Behaviour of Titanium and Nickel Alloys in Hot Forging Conditions, submitted at the IV Int. Conf. on AMST, Udine, September 1996.

[7] Bariani, P,F., Berti, G., D'Angelo, L. and Guggia, R., Determination of the Heat Transfer Coefficient in the Die-Billet Zone for Non-isothermal Upset Forging Conditions, submitted at the IV Int. Conf. on AMST, Udine, September 1996.