4th INTERNATIONAL CONFERENCE ON ADVANCED MANUFACTURING SYSTEMS AND TECHNOLOGY AMST'96,
UDINE, ITALY

DETERMINATION OF THE HEAT TRANSFER COEFFICIENT IN THE DIE BILLET ZONE FOR NONISOTHERMAL UPSET FORGING CONDITIONS.

P.F. Bariani, G.A. Berti, L. D'Angelo, R. Guggia

Dipartimento di Innovazione Meccanica e Gestionale
University of Padova, Italy

Key Words: forging, heat transfer, inverse analysis

ABSTRACT:

A number of tests were conducted to measure the heat transfer coefficient between billet and tool in non-isothermal upset forging conditions. Elastic deformation of cylindrical specimens between flat punches was used to verify the proposed procedure, whose applicability to large plastic deformation was verified in plane strain tests. This paper mainly insists on theoretical aspects and on presentation of axisymmetrical tests.

A fixture consisting of two flat 304 stainless steel dies was instrumented with type-K thermocouples to elastically deform 1100 Al cylindrical specimens at forging temperature, also instrumented with thermocouples.

A procedure was designed to measure heat transfer coefficient. Inverse analysis based on comparison between numerical and experimental data was applied. A fitting technique, based on adjustment of input data, was aimed at (i) reaching a satisfactory agreement between experimental and analytical results and (ii) determining a mean value for the heat transfer coefficient. Different operating conditions were tested.

1. INTRODUCTION

Some recent trends in metal forming as, for instance, forging of complex geometries and/or with close tolerances highlight the importance of studying interface phenomena: friction, wear, heat transfer. Recently at DIMEG a research work has been started on such topics. Heat transfer is a process which heavily influences tool behaviour at work. Tool hardness rapidly decays when temperature is higher than the selected recovery temperature. For this reason it is desirable that heat transfer between workpiece and tool is low in forging processes. According to lubricant producers desiderata, even a qualitative standard test could be useful to compare behaviour of different lubricants as concerns thermal barrier effect. In spite of these considerations and of remarkable works already developed [1-4], reliable data on heat transfer between tools and workpiece in forming processes are not available.

Direct measurement of the heat transfer coefficient is not possible, therefore non-direct ways have been developed, usually combining different techniques. When experimental tests are used, the starting point is measurement of temperature through thermocouples in selected points inside tools and workpiece. Location of measurement points inside the workpiece is difficult during forging tests because hot junctions shift from the original positions due to material deformation. As a consequence, a temperature vs time diagram obtained from a test does not refer to a point but to a point path.

The present work relates to a first set of experiments developed to evaluate the heat transfer coefficient at tool-specimen interface at forging conditions. Some simplifications were used:

(i) 1100 Aluminium was chosen as the specimen material to reduce test temperature and to use low cost and easy-to-work tool materials, in this case AISI 304 stainless steel,

(ii) Specimens are elastically deformed, then point shifts inside the specimen are so small that the position of measuring points inside the specimen can be considered known throughout the test.

2. PROCEDURE

To evaluate the heat transfer coefficient between punch and specimen an inverse analysis technique is used, based on combination of experimental tests and numerical simulations. The test chosen to this aim is upsetting of a round cylindrical specimen between flat punches.

In this test the heat transfer is supposed to be one-dimensional, from the specimen to the punches [1,2,3], that is to say the temperature is uniform on each plane parallel to the punch faces (cross sections). With this assumption two phenomena are neglected: lateral cooling and the distribution of the heat transfer coefficient at interface. Lateral cooling determines a radial temperature gradient in the components (punches and specimen), its influence increasing in slow tests. Pressure distribution is not uniform in this kind of test. It has been shown [5] that higher pressures determines higher values for the heat transfer coefficient. As a consequence, also the temperature distribution close to the specimen end surfaces is not uniform.

Locations for hot junctions were chosen taking into account the following requirements:

- thermocouples should not be too close to each other to reduce mutual influence,
- thermocouples should be far from lateral surface and close to interface to reduce influence of lateral cooling.

In addition, all thermocouples were set at the same distance from the axis, to reduce the influence of pressure distribution at interface.

Four thermocouples are used, two inside the specimen and two in one punch.

The procedure is made up of 5 steps, listed below:

1. conduction of the experimental test, whose output are the four temperature vs time diagrams given by thermocouples,
2. extraction of a "first attempt value" for the heat transfer coefficient, to be used for the numerical simulation. The "first attempt value" is based on the hypothesis of one dimension heat flow and constant axial temperature gradient inside components,
3. development of the numerical simulation and derivation of temperature vs time diagrams in "control points" corresponding to the thermocouple locations,

4. comparison between experimental and numerical diagrams to decide if the heat transfer coefficient should be increased or reduced in the numerical simulation,
5. development of a new simulation using the new value for the heat transfer coefficient. The procedure ends when a good agreement between experimental and numerical results is reached.

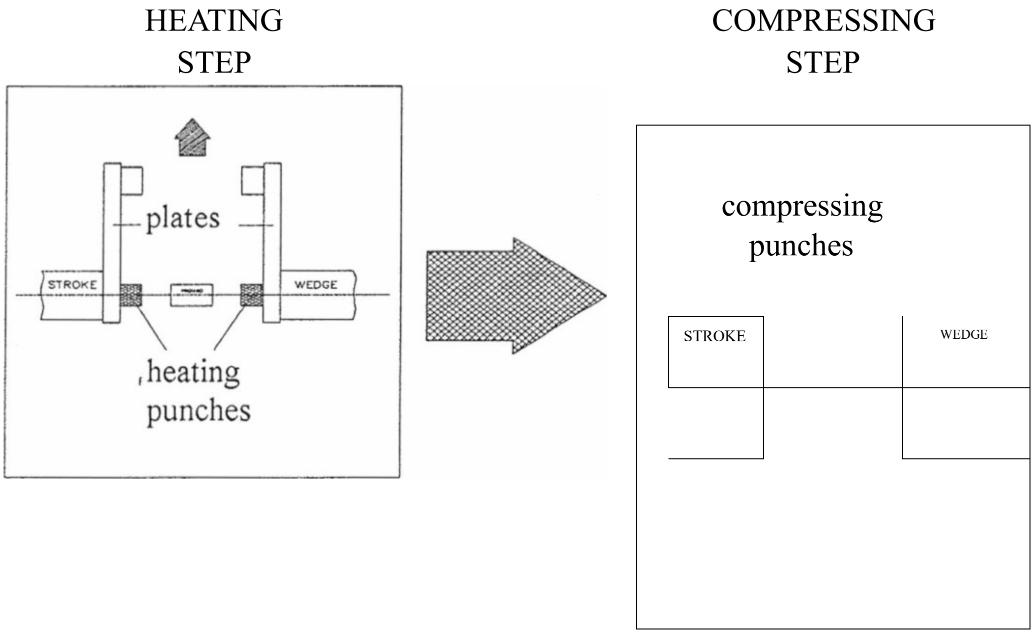

Fig. 1 - Main steps of the procedure.

3. **EXPERIMENTAL SET UP**

A Gleeble 2000 high temperature testing system was used to conduct experimental tests. Characteristics of the system useful for this work are:

(i) possibility to conduct both mechanical and thermal tests,
(ii) possibility to choose stroke and temperature control,
(iii) an integrated acquisition and registration system for thermal and mechanical data, and
(iv) its control software, suitable to command movement of non-standard devices.

Specimens are heated through Joule effect, the resulting temperature distribution being made up of isothermal cross sections inside the specimen. Two independently controlled hydraulic pistons (stroke and wedge) are used to deform specimens, the maximum load being 20 tons. Up to six thermocouples may be connected to the acquisition system, four type-K (chromel-alumel) and two type-S (platinum-platinum rhodium). In the presented tests four type-K were used.

To assure good test reproducibility a special equipment was used, designed by the authors. A feeding ram is used for correct specimen positioning. Two sliding stainless steel plates are inserted between hydraulic pistons and punches. Their movement is possible through a pneumatic piston, software controlled. Plates are water cooled for high temperature tests. The resulting assembly allows use of two different couples of punches, one copper couple (electrodes) for heating specimens and one stainless steel for deforming them. This solution was chosen because heating by Joule effect causes increase of temperature in punches as well as in specimen. In that case punches would reach much higher temperatures and operating conditions during deformation would be farther from industrial forging conditions.

The testing procedure is shown in Fig. 1. The specimen is first carried by the feeding ram between the electrodes (heating step). Here it is heated till 430 °C, a usual forging temperature for aluminium. At the end of the heating step, the specimen is kept in position by the ram while the plates slid to face the punches to the specimen. The last steps are compression to the programmed stroke and specimen unloading.

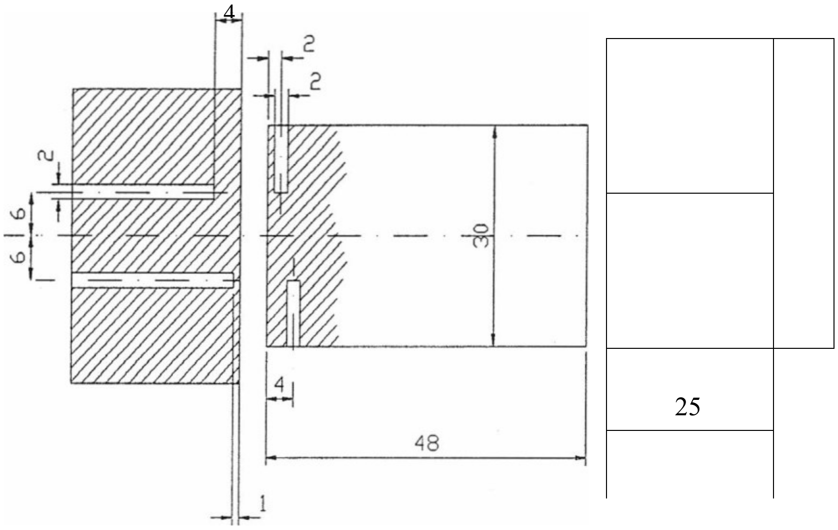

Fig. 2 Test components geometry.

Fig. 2 shows the test geometry. The specimen is a Φ30 x 48 mm aluminium cylinder in which two holes were drilled at different distances from the end surface. The two punches are Φ40 x 25 mm, of which one was drilled to insert thermocouples. All hole bottoms are 6 mm far from the axis, on different directions to reduce mutual influence. The distortion of the thermal field due to

(i) heat conduction along the thermocouple wires and
(ii) holes for the thermocouples was calculated according to Attia and Kops theory [6].

It results that the main distortion is due to thermocouples farther from interface, but still acceptable.

For the selected thermocouples 40.25 mm wires were used, having a time constant of 0.016 seconds. The time constant was evaluated moving the hot junction of a thermocouple from environment to boiling water. To connect thermocouples to components, the hot junction results from:

(i) spot soldering thermocouple wires together at one end,
(ii) setting it in position and
(iii) soldering it at the bottom of holes.

Both ceramic and Teflon sheathes are used for thermocouples, ceramic inside holes because it resists high temperatures and flexibility is not required, Teflon is used outside holes. Connection between hot junction and hole bottom was strengthened by means of a special cement which also contributes to thermal insulation.

4. NUMERICAL SIMULATION

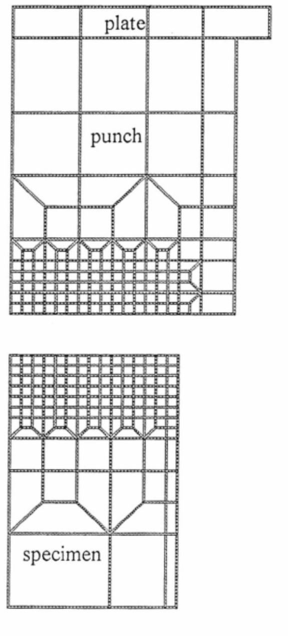

Fig. 3 - Simulation mesh

A coupled thermal-mechanical simulation of the test was developed using ABAQUS. True stress-true strain curves for both punch and workpiece materials were developed using the Gleeble system. Punch material was modelled as simply elastic, the elasticplastic model was considered the most suitable for the specimen. It was taken advantage of existing symmetries and one quarter geometry was analysed. The utilised mesh is shown in Fig. 3. The simulation is made up of two steps: (i) elastic compression of the specimen at the starting temperature of 420 °C (to take into account specimen cooling during transfer from heating to the compressing punches), stroke and speed being the same as in the real test, and (ii) simple contact between specimen and punches for 30 seconds. Four control points were selected corresponding to the position of the four thermocouples. Some experimental tests were conducted to establish starting temperature distribution on the boundary of both punch and specimen. A plate at constant temperature is used to simulate punch water cooling. To select a value for the heat transfer coefficient for the first run, a specific procedure was used, as presented below:

- calculation of the heat flow in the specimen and in the punch:

$$q_s = \frac{\lambda_s}{l_s}(t_{s1} - t_{s2})$$

$$q_p = \frac{\lambda_p}{l_p}(t_{p1} - t_{p2})$$

where: and qp are the specific heat flow inside, respectively, the specimen and the punch,

λ_s and XP are the thermal conductivity of specimen and punch materials,

Is and Ip are the axial distance between thermocouples, respectively in-

side specimen and punch, tsl, to, tpl, tp2 are the temperatures measured by thermocouples at the end of the test.

- extrapolation of surface temperatures at interface:

$$= t_{s2} - \frac{q_s}{\lambda_s} l_{s2}$$

ss

sp pi p^i

where: tss and tsp are the interface temperature of, respectively, the specimen and the punch,

10 and Ipl are the axial distance of thermocouples s2 and pl from the interface.

- evaluation of the specific heat transferred at the interface: q = (qs +qp)/2
- evaluation of the heat transfer coefficient:

$$K = \frac{q}{t_{--} - t_{--}}$$

SS sp

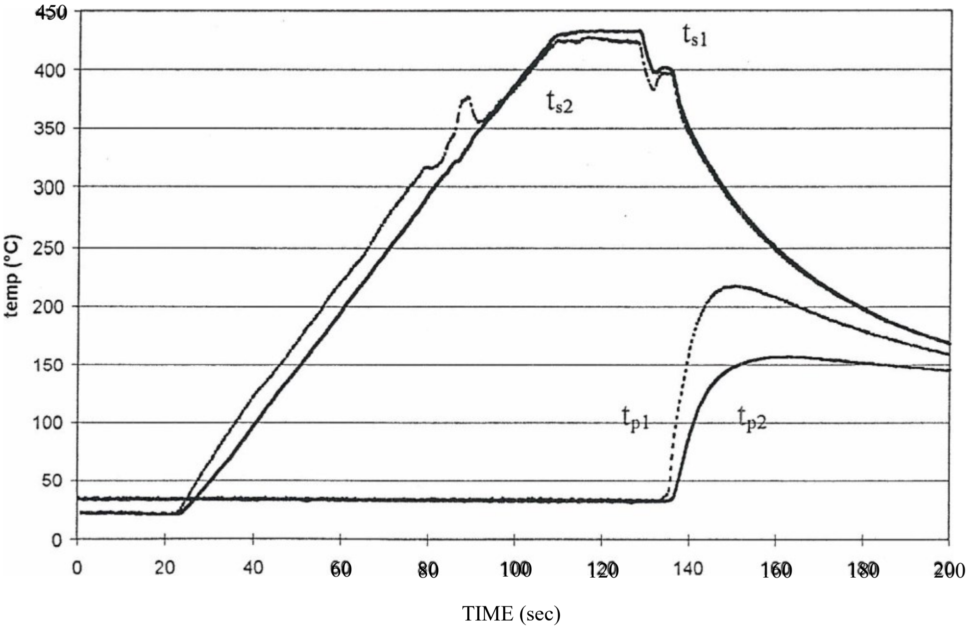

Fig. 4 - Temperature vs. time diagrams from a test

The coefficient has similar values in Tl and T3. In T2 thermocouples are closer to the lateral surface, then one possible explanation of the very high value for K could be the influence of lateral cooling inside specimen, having much higher thermal conductivity than the punch. As concerns the value relevant to T4, it was demonstrated also in other kinds of test that the heat transfer coefficient increases when interface is lubricated; this result is confirmed in unpublished reports of other researchers working in the same field.

Test	K W/m ^{20} C
Tl d=6 mm, d int., room tem	3050
T2 d=10 mm, d int., room tem	6700
T3 mm, d int., 75 ^{0}C	2700
T4 d=6 mm, MOS2, room tem	4500

Table 1 - Values of the heat transfer coefficient in different operating conditions.

CONCLUSIONS

A procedure has been presented to measure the heat transfer coefficient in laboratory tests at tool-workpiece interface. Inverse analysis is used, based on comparison between numerical and experimental data. The procedure was applied to the elastic compression of cylindrical specimens between flat punches. Results have been presented relevant to application of the procedure to tests with different operating conditions.

REFERENCES

1. Burte, Y.-T. 1m, Altan T., Semiatin S.L., Measurement and Analysis of Heat Transfer and Friction During Hot Forging, Transactions of the ASVIE, Vol. 1 12, Nov. 1990.
2. Lenard J.G., Davis M.E., An experimental Study of Heat Transfer in Metal-Forming Process, Annals of the CIRP, Vol. 41/1/1992.
3. Burte, Altan T., Semiatin S.L., An Investigation of the Heat Transfer and Friction in Hot Forging of 304 Stainless and Ti-6Al-4V, Proceedings of Symposium of Advances in Hot Deformation Textures and Microstructures, 1993.
4. Malinowski Z., Lenard J.G. and Davis M.E., A study of the heat-transfer coefficient as a function of temperature and pressure, J. Mat. Proc. Tech., Vol. 41, 1994, pp. 125-142.
5. Chen B K., Thomson P.F. and Choi S.K., Temperature Distribution in the Roll-Gap during Hot Flat Rolling, J. Mat. Proc. Tech., Vol. 30, 1992, pp. 115-130.
6. Attia M.H., Kops L., Distortion in the Thermal Field Around Inserted Thermocouples in Experimental Interfacial Studies-Part 2, J. Eng. For Ind., Vol. 110.
7. Zardo D., Characterisation of interface between work material and tool in hot forging , .heat transfer coefficient determination, Graduation Thesis, DIMEG-University of Padua, 1995 (in Italian).