PHYSICAL SIMULATION USING MODEL MATERIAL FOR THE INVESTIGATION OF HOT-FORGING OPERATIONS.

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ABSTRACT:

Physical simulation using model materials is an effective technique to investigate hot forging operations of complex shapes and can be a significant alternative to a numerical approach (F.E.M) in the preliminary phases of process design. This approach is suitable to evaluate die filling, material flow, flow defects and to predict forging load system. The paper is focused on i) presentation of the equipment, developed by the Authors, and ii) its application to model the hot forging of a crane link.

The developed equipment is suitable to replicate forging operations using wax and lead as model materials, as well as to reconstruct the system of forces acting on the dies.

Characterisation of model material and forged steel has allowed to obtain an estimation of real forging load at each stage of the sequence.

1. INTRODUCTION

Physical simulation of forging operations consists of different techniques aimed to i) reproducing operating conditions using real materials on simple geometry specimen [1,2], ii) simulating the forming process using either real geometry and model materials (waxes, plasticine, lead) or visioplasticity techniques [31 and analysing flow behaviour.

The paper presents some progresses in the investigation of forming processes model materials and its application to the study of a hot forged crane link. The model materials present i) a lower load for deformation, if compared with real forged materials, and ii) the deformation can be performed at room temperature, instead of hot forging temperature. For these reasons the laboratory tests are faster, easier and less expensive than a sub scale production process. Furthermore, the dies utilised in the test and reproducing the geometry of real dies can be manufactured in resin, aluminium, Plexiglas (in the case of waxes and plasticine) or carbon steels (in the case of lead).

Investigations based on model material can be focused on different aspects, such as flow behaviour (die filling, defects recognition), forming load requirements [4], parting line location, flash design, die attitude optimisation, billet location, etc.

2. PHYSICAL SIMULATION TECHNIQUE

A new facility has been developed [5] and installed at DIMEG, University of Padova, devoted to physical simulation using model materials. It consists of a 2000 kN lab press (named Toy Press and shown in Fig. l) equipped with a multi-axes force- and moment transducer. The transducer, a 3-plate die set with 3 piezo-electric three axial load cells, connected to a PC-based acquisition system, provides, during 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, reconstructing them from the nine load cells signals. Different plots can be obtained, such as force and moment versus time/die stroke, attitude of resultant of the forming force versus time/die stroke, as well as application point of resulting force mapped over the cycle [6].

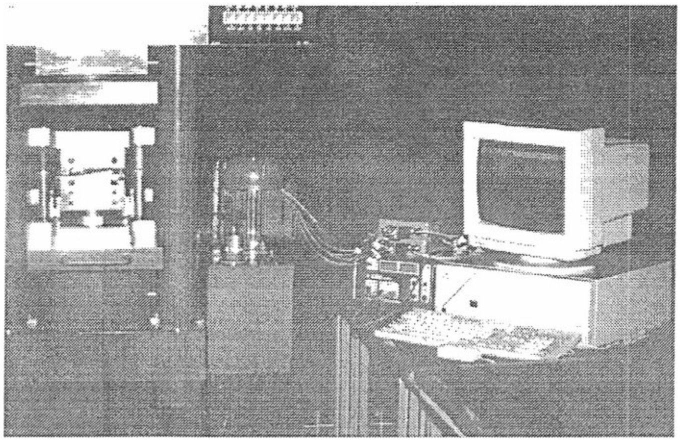

Fig. 1 The equipment for the reconstruction of forces and moment over the forging cycle.

The direct analysis of the attitude of resultant and mapping of its application point can suggest modification of die attitude, parting line location and billet positioning, in order to reduce lateral forces and moment acting on the dies.

Force and moment history over the forging cycle allow the recognition of symmetries/asymmetries in the dies and in the flow.

A comparison among simulations obtained using alternative forming dies gives information on effectiveness of solutions adopted in die design [7, 8] relevant to die filling, forming load reducing, defects eliminating and flash minimisation. Defects in material flow and in the die filling can be recognised by visual inspection of model material preforms and using a multi-colour layered billet. This approach results to be particularly useful in the preliminary phases of process design, when alternative solutions should be rapidly evaluated in order to determine the optimal one, without manufacturing expensive die sets and testing them at operative conditions.

An extreme care should be taken when the load of real forming operation has to be predicted. The following rules should be applied:

plastic behaviour of model material should reproduce as close as possible, in reduced scale, the real material behaviour at forging conditions, an equivalent effect due to the lubrication should be reproduced at the die-material interface using oil, solid soap, plastic films, etc.

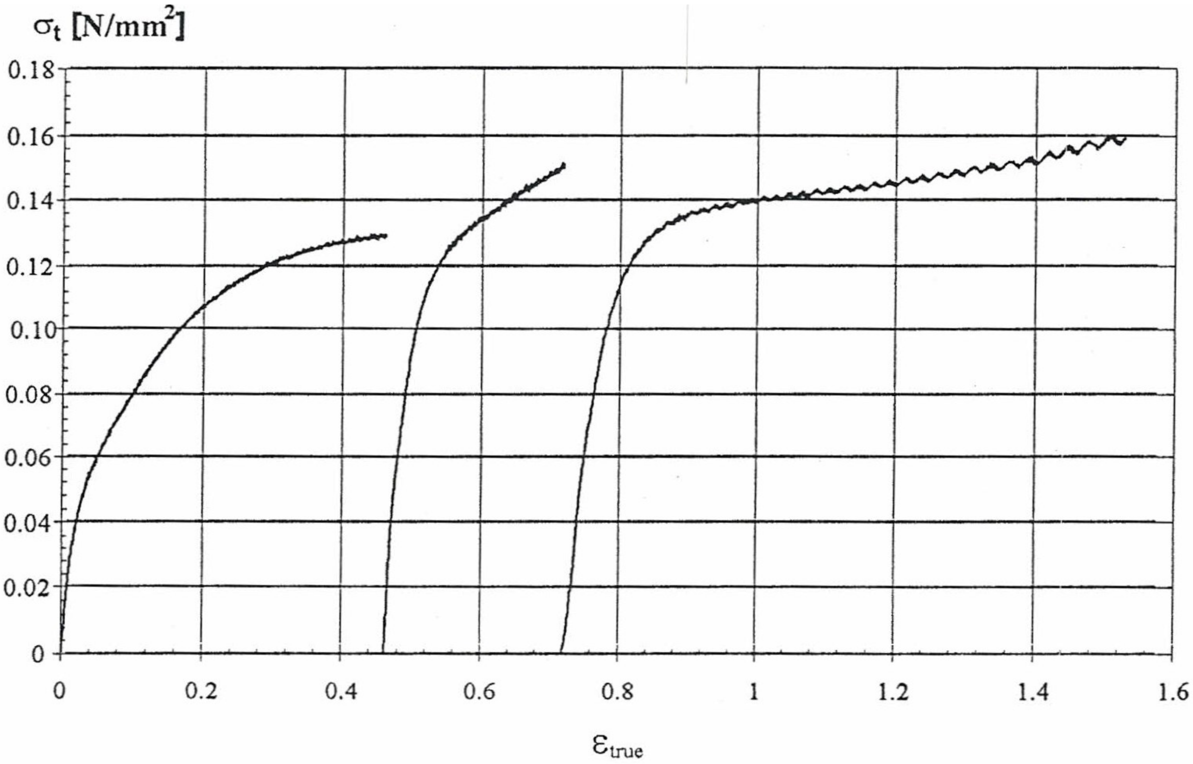

Fig. 2 Multi-step true stress - true strain curve of the wax (model material).

As concerns model material characterisation, cylindrical specimens have been upset; good lubrication condition should be assured in order to minimise the barrelling, otherwise the state of stresses is three-axial. When true strain (ε) is above 0.4, lubrication becomes not effective; therefore, the characterisation test should be splitted into a number of steps, each one performed to a strain less than 0.4 and reconstructing the lubricating film before each step. The resulting multi-step true stress-true strain curve is presented in Fig. 2.

3. APPLICATION EXAMPLE

Physical simulation using model material is applied to the study of a hot forged crane link. This new-design large crane link for earth moving machines (see Fig. 3) will be produced on a three stage vertical hot former. Main difficulties in forging this crane link are relevant to die attitude and too high forming forces compared with the press loading capacity.

Material is 35MnCr5 steel forged in the range 1200-1250°C. Forging sequence dies used in physical simulation are shown in Fig. 4; a flash trimming stage, not shown, ends the sequence. The starting billet is 100x100 mm (square section), 350 mm long.

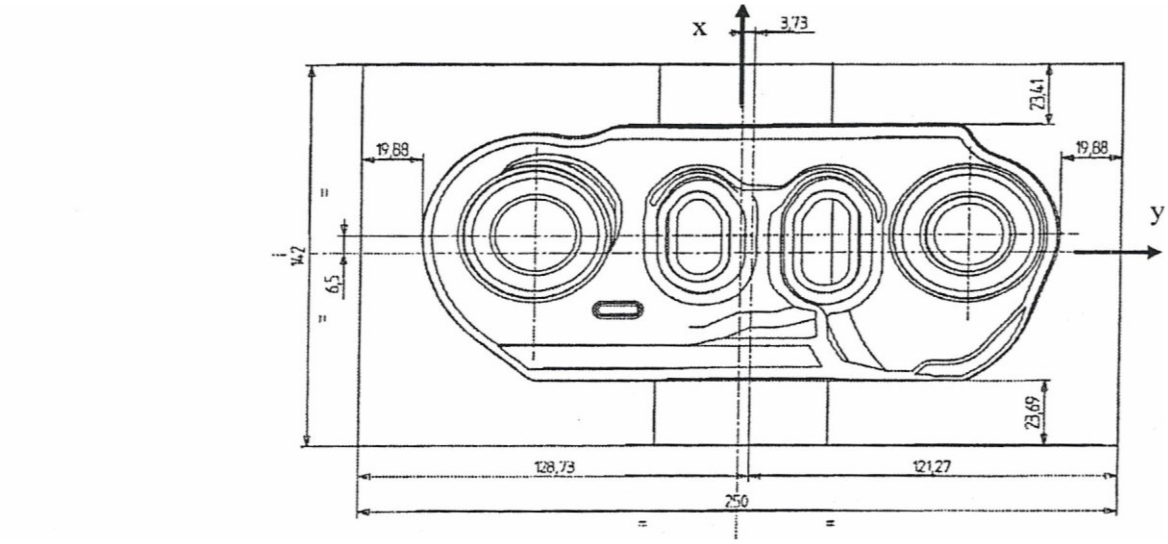

Fig. 3 Top view of the new-design crane link.

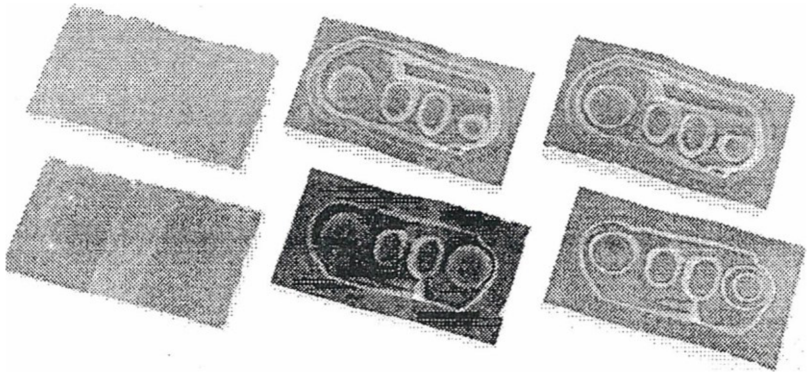

Fig. 4 Dies for the simulation of hot forged crane link (3 forming steps preforming, blocking and finishing)

In order to investigate both die attitude and required forging force, dies for physical simulation have been NC manufactured using a resin in half size scale respect to designed dies for real process.

As concerns model material, a wax has been used which offers a behaviour similar to the real material. In Fig. 5 the true stress-true strain curve of wax is compared with the true stress-true strain curve of 35MnCr5 steel (T=1200 °C, $\dot{\varepsilon}$ =11.0 1/s). The curves of this steel have been obtained using the Gleeble 2000© thermo-mechanical simulator in the range of temperature, strain and strain rate present in the process.

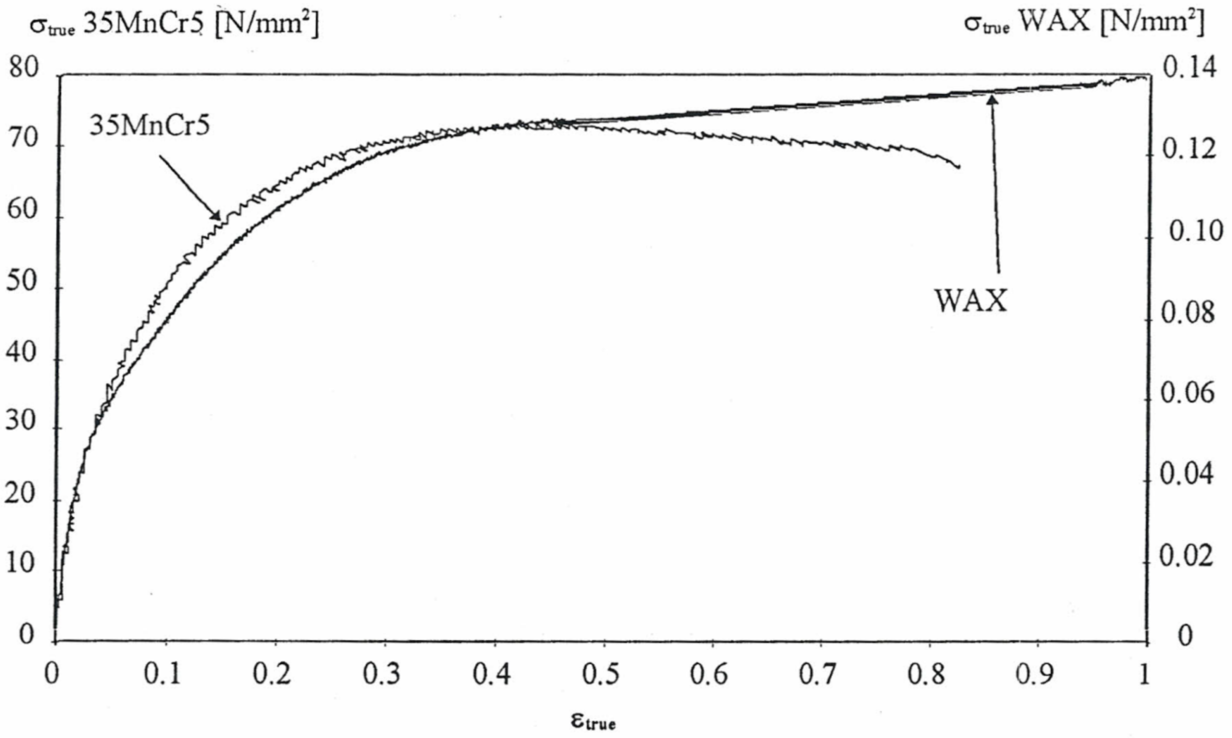

Fig. 5 Comparison of true stress - true strain curve of 35MnCr5 steel (T=1200°C, =11.0 1/s) with wax curve.

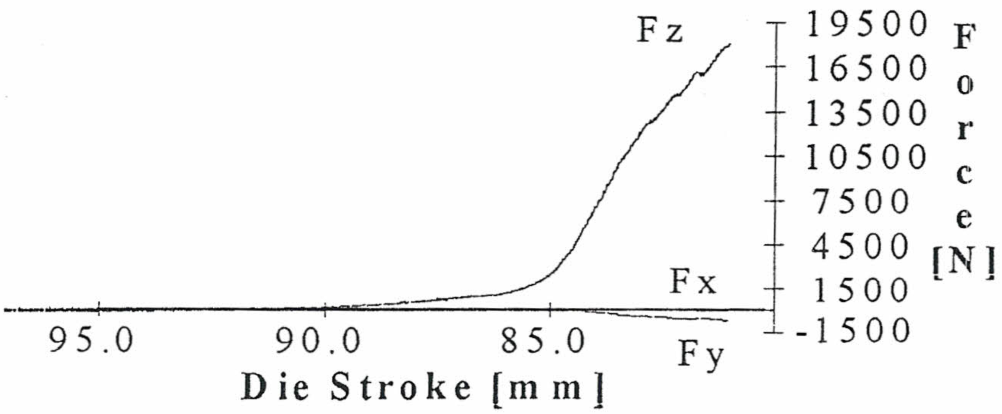

Fig. 6 History of 3 force components.

A direct analysis of forces, torque and application point plots gives information on correctness of partition line definition, dies orienting and billet positioning. The lateral forces (Fx, Fy) in the finishing die, shown in Fig. 6, are negligible and main contribution to resultant force is due to the Fz component. The moment My and Mz (see Fig. 7) are low due to the facts that the die is symmetric respect to the y axis (My→ 0) and the lateral forces (Fx, Fy) are negligible (Mz→0). Presence of moment Mx can be explained by the fact that dies parting line is not in a single plane.

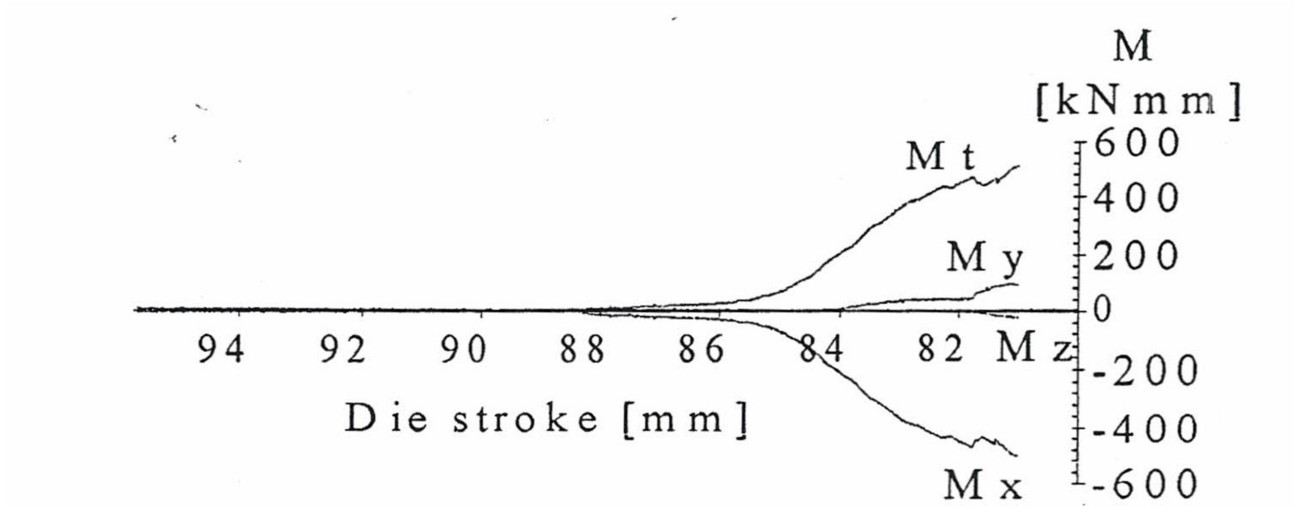

Fig. 7 History of 3 moment components.

As concerns application point of resultant force, it can be recognised in its mapping over the cycle (Fig. 8), that i) it is located near the gravity centre of the die (origin of reference system), and ii) it becomes closer to the point (-12,20) during the stroke of the die.

Based on this analysis, it can be confirmed that the dies are well designed, because the lateral forces are negligible, moments are low and application point of resultant is close to the gravity centre of the die.

In order to estimate maximum of force (Fmax) in real process different approaches can be chosen.

The first one [3], based on similitude, requires the satisfaction of different conditions depending on type of processes:

- plastostatic: strain-hardening exponent of real material should be the same as the model material one (cold forming), or strain-rate exponent of real material should be the same as the model material one (hot forming),
- dynamic: (when inertia stresses are important for the plastic deformation) the following condition (equivalence between kinetic energy ratio and internal work ratio) should be satisfied

$$(1/2 \cdot Vol \cdot \rho \cdot v \cdot v)_{model} / (1/2 \cdot Vol \cdot \rho \cdot v \cdot v)_{real} = (Vol \cdot \sigma_0 \cdot \varepsilon)_{model} / (Vol \cdot \sigma_0 \cdot \varepsilon)_{real}$$

where

ρ is the density, v is the speed, Vol is the volume of the workpiece, σ_0 is the flow stress, ε is the strain.

The fulfilment of similitude conditions allows the determination of load for real process (Freal) on the basis of

$$Freal(\varepsilon) = Fmodel(\varepsilon) \cdot \sigma_{0real}(\varepsilon) / \sigma_{0model}(\varepsilon)$$

The second approach [9], which gives a very approximate estimation, is based on the following assumption: the maximum of force is reached at the end of the forming process, when the dies are filled and flow of material is essentially located in the flash. In this case the following relation can be used

$$F_{max} = K_f \cdot A \cdot \sigma_f$$

where A is the projection area in the forming direction including the flash,

K_f is the complexity factor,

σ_f is the material flow stress.

The complexity factor mainly depends on geometry of dies and preforms. Taking in account this simplification, the K_f factor can be considered independent from material and it can determined as

$$K_f = F_{max\_model} / (A_{model} \cdot \sigma_{fmodel}) = 5.8$$

using the obtained from physical simulation and σ_{fmodel} as the flow stress of the model material. The maximum of force in the real process (F_{max_real}) results to be

$$F_{max\_real} = K_f \cdot A_{real} \cdot \sigma_{freal} = 28900 \text{ kN}$$

$$F_{maxr} = K_f \cdot A_r \cdot \sigma_{fr} =$$

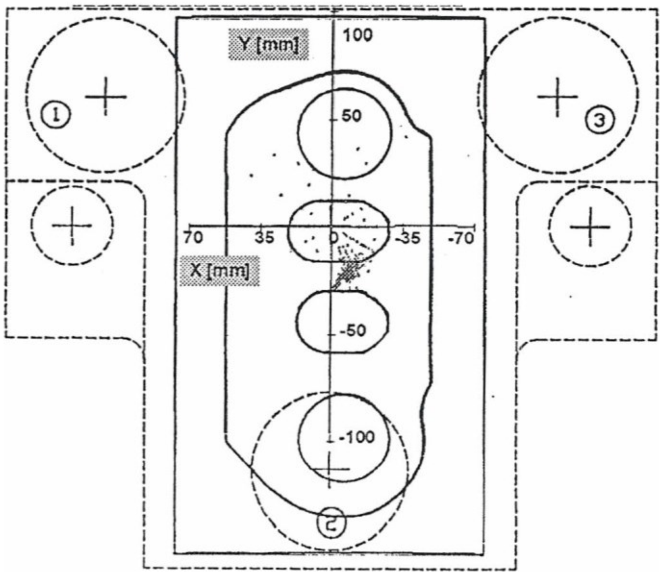

Fig. 8 Application point of resultant force.

CONCLUSIONS

A recent application of physical simulation technique to the analysis and modelling of hot forging operations has been presented. The paper has illustrated the developed equipment and the procedure utilised in the investigation of hot forming by physical modelling, which includes the monitoring of force-and-moment history over the forging cycle of complex parts. The application of this technique to the forging of a crane link has been presented, demonstrating the power of this approach in the preliminary phases of process design if compared with expensive trial sub scale production or time consuming F.E. simulations.

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