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METHOD TO ESTIMATE WORKPIECE-DIE HEAT TRANSFER COEFFICIENT ON PRECISION WARM FORGING PROCESS

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Summary

Different fail modes are responsible for the end of hot forming die sets service life, being one of them caused by the temperature oscillation during the process. A method to estimate workpiece-die heat transfer coefficient is presented using experiment and FEM simulations. Experiment, done during the actual process, registers the temperature in one point of the dies. Simulations, using finite elements method, show the die heating along time for various heat transfer coefficients. The simulation results are compared with the experiment validating the coefficients, which are confronted with other sources. The die temperature profile, result of choose coefficient, is showed.

1 Introduction

In the warm precision forging processes of CV Joints, great part of the costs are involved with raw material to manufacture the die set, then an increasing research for optimization of the die sets and work conditions to increase dies life has been carried. In such processes it is required an excellent superficial quality of the parts as well as excellent dimensional tolerance. As a consequence, any die defect can cause some kind of superficial scratches in the parts making impracticable its use, causing the end of its life. Therefore, reasonable knowledge about the factors that involve the process is important.

Amongst the factors that influence on the die life are materials microstructure, heat treatment and superficial treatment, project, project conditions [1] and process parameters.

The main failure mechanisms that occur on warm precision forging die sets involve wear, thermally and mechanical induced plastic strain, thermal fatigue, cracks, micro cracks and tempering. The tempering, that is the loss of hardness decurrent of high temperatures, is influenced by the absolute temperature, being able to cause spalling and die deformation.

The micro cracks and cracks occur due to thermal fatigue, suffering strong influence of temperature cycle. Cracks are caused also by mechanical loading.

An important tool to develop forming dies, as also for the part project, is the numerical simulation through the finite elements method.

The necessary knowledge of the contact conditions between workpiece and die is important to get accurate results in numerical simulations. In general, the contact conditions in a process are determined by friction shear stresses, contact normal stresses, relative sliding velocity between contact bodies, the heat transfer and the superficial temperatures of workpiece and die [1].

It is not possible to carry a direct and accurate measurement of the workpiece temperature during the process, nor to measure the superficial dies temperatures. Measurements of temperature in certain points in the interior of dies can be taken to validate the simulations.

Obtaining a profile of simulated temperatures that most closely describe the measured temperatures in the real process, it will be able to take these parameters of this simulation as being the parameters that most closely to the reality, being the heat transfer coefficient between workpiece-die one of them.

The beginning of the process is characterized by transient regime when the die starts to forge and its temperature increases since the environment temperature until an almost static range of temperatures. Thus it oscillates between a minimum and a maximum, characterizing each blow of the forging press, reaching the maximum right after the die contact with the workpiece and the minimum when it loses heat to environment and to the cooling refrigerant.

The optimum condition is to minimize the heat transfer coefficient between workpiece-die. Thus can be reduced the oscillation of the temperature during steady state, minimizing the thermal fatigue effect and decreasing the absolute temperature on the die set.

The main objective of this study is to reach consistent values for the heat transfer coefficient between workpiece-die, to later study ways to minimize it, decreasing thus the thermal gradient in the dies and, as a consequence, minimizing the fatigue effect.

2 Failure modes

The CV joints are manufactured in four stroke stages. In the first three stages direct extrusion occurs, occurring inverse extrusion at the fourth and last stage. The workpiece is made of SAE 1050 carbon steel and the initial temperature is approximately 900°C. The workpiece and the final shape of the part are presented at Figure 1.

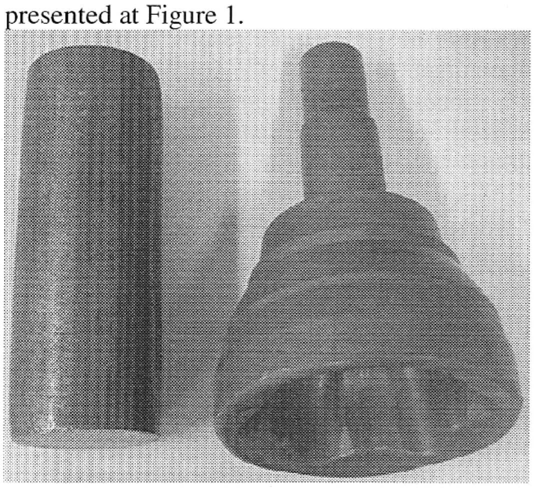

Figure 1 – workpiece and final shape part.

The die set of the fourth stage is presented in Figure 2, where it can be noticed the complexity in the geometry of the punch, in which the present study is focused. The forging press has a loading capacity of 2.000 ton, and operates at 20 blows per minute for the part at present study. However the production is of 15 parts per minute because for each three blows only two parts are produced.

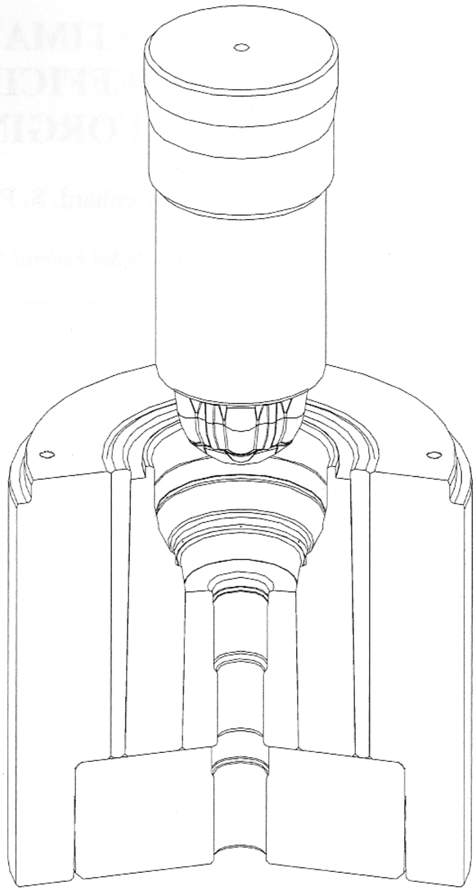

Figure 2 – Forging 4th stage die set.

The dies are made of hot work modified chromium-molybdenum DIN 1.2367 steel, with nominal hardness between 54 and 56 HRC. It must have conditions to provide excellent superficial quality in the parts and possess properties that assure a die set long life.

Depending on the lubrication parameters the dies can present different types of failure that could shorten or extend the dies life. Micro cracks start to appear in the dies surface due to thermal fatigue and grows with elapsing of the process, resulting in mechanical fatigue cracks.

After approximately 2,000 blows, cracks are formed in the nose of the punch, and this is a failure mode that characterizes the end of service life, as shows Figure 3. Still in Figure 3, it can be seen, in track area, beyond cracks, an occurrence of galling wear and mechanical fatigue.

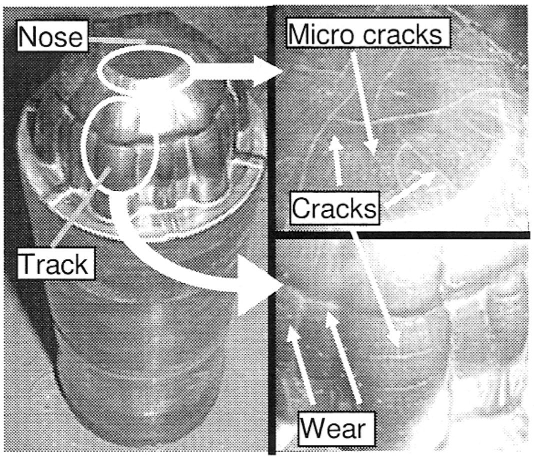

Figure 3 – Warm precision forming punch failure modes.

3 Practical Experiment

The measurement system used has only one channel, which only allows the acquisition of temperatures at one single point. Dies with a hole are made for a thermocouple insertion for the accomplishment of the temperature measurement along the time, as shows the scheme of Figure 4.

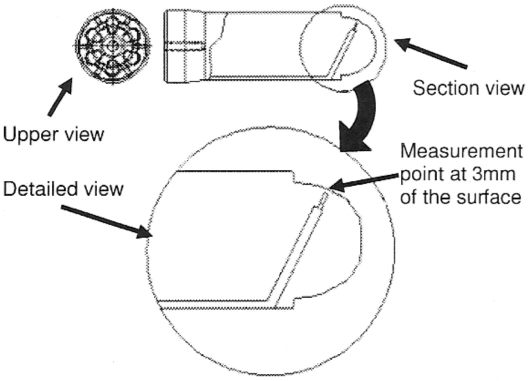

Figure 4 – Temperature measuring tool scheme.

In Figure 5 can be seen the punch whose temperature was logged.

Figure 6 shows a schematic drawing of the die set assembly when the press ram is at the bottom end. The internal hole can also be seen in the punch with thermocouple in position, 3mm far from the track surface. The thermocouple used was a K type with 2mm of external diameter and grounded metallic encapsulation.

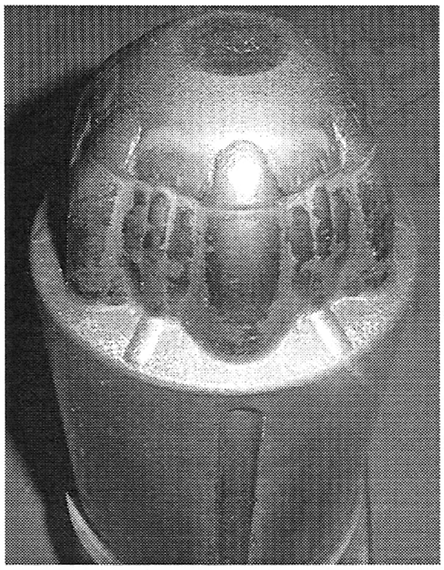
Figure 5 – Temperature logged punch.

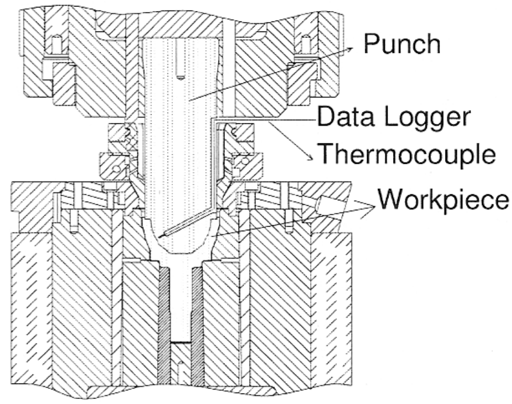

Figure 6 – Warm forging 4th stage detailed cutting section, showing the measurement system.

4 Numeric Simulation

4.1 Heat transfer theory

In the interface workpiece-die the contact is not perfect due to roughness, to the thickness of the lubricant film, to composition of the lubricant and other factors that occur in the involved interfaces. This is expressed through a global coefficient that intends to simplify the phenomenon description, called contact resistance. As the resistance involved in the forging process is, in general, small, inverse is adopted, or either, conductance or, more specifically, the workpiece-die heat transfer coefficient [2]. With this coefficient is possible to determine the heat flow at interfaces and to predict the temperatures that the tools reach during the process. As the determination of this coefficient on an analytical method it becomes impracticable due to amount of involved factors, the most practical way to determine is comparing the calculated temperature profile with the measured temperatures iteratively until desired precision is reached.

As the focus of this study is turned to the die set, tools considering heat transfer are employed, i.e., the punch has the property to change the temperature along the time. Two heat transfer modes are considered, the convection with the environment and conduction between workpiece-die. For the convection [3]:

$$q''_{conv} = \bar{h} \cdot (T_s - T_\infty)$$

where q''_{conv} is the convection heat transfer rate per area in W/m^2, $\bar{h}$ is heat transfer coefficient to the environment in W/m^2.K, T_s is the dies surface temperature and T_∞ is the bulk air temperature in the neighborhood.

For the conduction between workpiece-die is used:

$$q''_{cond} = H \cdot (T_w - T_t)$$

where q''_{cond} is the conduction heat transfer rate per area in W/m^2, H is heat transfer coefficient to the workpiece-die in W/m^2.K, T_w is the workpiece surface temperature and T_t is the die surface temperature.

Figure 7 presents the detailed scheme of the simulation, where the geometries, heat transfer modes and the temperature measurement point for comparison with the experiment are indicated.

In the analysis in question the punch must be considered deformable, thus it can suffer temperature change as function of the time. This does not occur with the rigid die, being shaped by curves that facilitate the problem solution.

On workpiece-die interface, conduction heat transfer mode was considered only. On punch-air interface, convection heat transfer mode was used to take to account the punch cooling through the lubricant-cooler and the air.

The punch cooling through lubricant-cooler and air was modeled by convection, considering the software doesn't have a specific model for lubricating.

4.2 The software

The computational FEM analysis package used is the MSC.Superform 2005®. This software approaches the manufacture process of bulk formed parts and detailed die set analysis, however is just for only one workpiece. To study the continuous production influence on the dies, difficulties appears. To avoid these difficulties, jobs are created which is possible to inherit the previous die conditions (for example, temperature) along processes. With this subterfuge it can be considered that the punch, initially, is at room temperature and with successive forming processes it heats due contact with the hot workpiece. The workpiece heat comes from initial heating and, during forming, friction due workpiece-die relative slide movement and plastic strain also generates heat. The cooling occurs due contact with the lubricant-cooler and with neighborhood air. Thus, results, that show how temperature distributes in the punch, could be obtained. Then, successive processes are simulated for each ram blow, recording the temperature oscillation as function of time. This oscillation occurs due to the die global heating, to the alternate contact with the workpiece and to the lubricant-cooler and air contact (graphite-oil based).

This process is repeated successively during the transient regime until the average temperature increasing is enough small, indicating a steady state behavior.

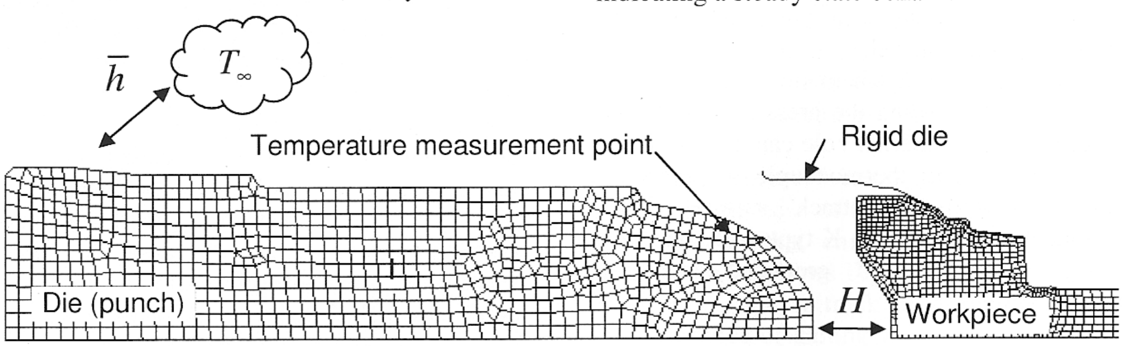

Figure 7 – Die mesh and curves, workpiece mesh and heat transfer modes.

4.3 Inverse method

As the die temperatures profile during the process is unknown, various simulations are carried through consecutively and thus the die is exposed to various blows along the time. At the end of each blow the die temperatures information is transferred to the next blow simulation, and thus successively. The punch measured temperature, through the experiment, is compared, along of the time, with simulations.

5 Results and discussions

The graph below, Figure 8, present results of the experiment. The punch temperature at the indicated point is registered and plotted, in Celsius degrees, along the time, in seconds.

It is observed that the temperature of the experiment it stabilizes around 200s with 306°C in average and presenting amplitude variation between a peak and a valley of each cycle of 13.2°C. Other curves simulate the heating for some combinations of $\bar{h}$ and H, as Table 1.

The curve (a) was neglected, because its high amplitude, around of 30.5°C, as a consequence of the high values of $\bar{h}$ and H. The curve (b) shows smaller amplitude, however the temperature is very high when balance is reached in result of a high $H/\bar{h}$ quotient. Curve (c) presents amplitude of 18.4°C and average of 332.7°C, which represents a closer result with the experiment.

Table 1 – Thermal Parameters employed on simulated curves.

	(a)	(b)	(c)
$\bar{h}$ [W/m^2.K]	650	170	150
H [W/m^2.K]	15,000	9,000	5,000

At beginning of the curve (c) a temperature increasing does not follow the experiment curve. Once the heat transfer coefficient (H) depends of die and workpiece surfaces temperatures and the temperature difference between them is much bigger at the beginning so the heat transfer coefficient it is also bigger. Along the time its experience a decrease until values around H and a global temperature profile come to a steady state.

The objective of the simulation it is not in tracing, accurately, the experimental curve, but to obtain coefficients that balance the die temperatures profile in a steady state.

5.1 Simulated die temperature profile

In Figure 9 the punch temperatures profile is shown for the heat transfer coefficients that most agreed with the practical experiment taking as base the single point of measurement.

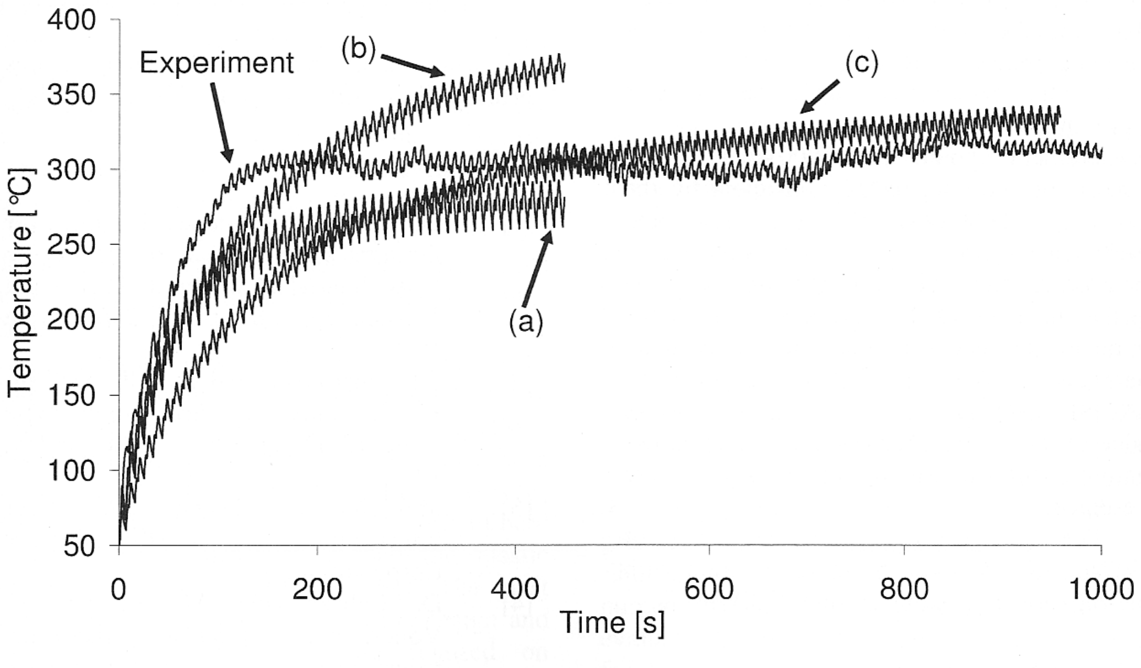

Figure 8 – Simulation results in comparison with the experiment data.

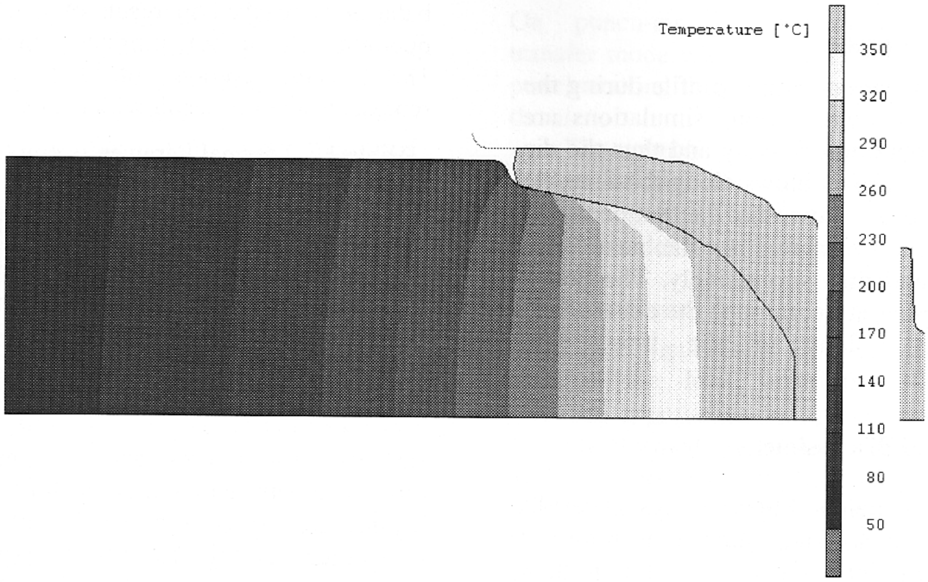

Figure 9 – Temperatures profile in the punch.

6 Conclusions

Experimental determination of die superficial and forming parts temperatures are very difficult, therefore the workpiece suffers plastic strain and direct measurement of the temperature is not possible. The procedure followed in this study allows estimating of the warm forging die set temperatures profile and consequently its superficial temperature. Such procedure involves the interaction between FEM simulations and practical experiments of the actual process of forging.

For this case the H coefficient that most approximate the temperatures average in the measurement point is 5,000W/m^2.K. In comparison with suggested coefficient by the software, 25,000W/m^2.K, the estimated coefficient seems to be much smaller. A speculation about this high transfer rate could be that it is adjusted to processes where the lubricant is not so efficient to insulate thermally as in the experiment. CALISKANOGLU et al. [4] results shows value of H around 6,000W/m^2.K, this shows more coherence with the results here presented.

The convection coefficient $\bar{h}$ of 150W/m^2.K reveals to be more coherent with the software suggestion, around 200W/m^2.K.

7 Future development

A system with more channels capable of acquire temperatures in more than one point simultaneously, thus a temperatures profile in the dies can be described with better resolution of the actual process.

A sketch of thermocouples positioning on this new system is shown in Figure 10.

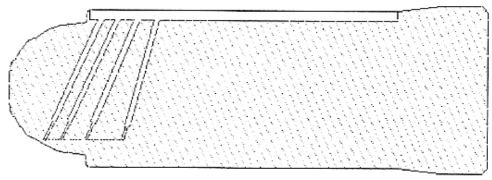

Figure 10 – Sketch of thermocouples positioning.

Thus it assures that the temperatures profile will be better discretized in the punch.

References

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