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IR thermography application in studying phenomena in warm extrusion tooling

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Abstract

Temperature of warm extrusion tools has been measured by means of both thermocouples as well as thermographic camera. A series of workpieces was extruded and changes in temperature during production were continuously recorded. Experimental results were compared with results of numerical simulation of heat exchange by means of FEM. An influence of temperature variations on physical and mechanical properties of tool steels was taken into account in the analysis of tool behaviour.

1. Introduction

Warm working is a demanding technology from process parameters' points of view. Especially temperature of a tool and temperature of a billet should be kept in a narrow range of specified values to avoid numerous problems. An increase of tool temperature in production would result in change of mechanical properties of tool material and finally this tool could fail during deformation process. If the temperature of a tool is too small, then the higher load which would be necessary for plastic deformation of a billet could result in overloading of the tool. In effect, knowledge about dispositions of temperature in the tools for extrusion is essential to be able to ensure: high level of endurance and durability of the tools, proper lubrication, to predict changes of the tools shapes and dimensions. These parameters decide about quality of products [1,2].

An exact control of tool temperature is technically troublesome; there are some limitations with placing temperature sensors just at the working surfaces of a punch and a die. IR Thermography provides some interesting possibilities of controlling tool temperature without any change in tool design though this technique is limited to visible surfaces only.

Cold and warm extrusions are generally associated with close dimensional tolerances and good surface quality. In the case of forward extrusion, the product geometry is affected mainly by properties of deformed metal and tool behaviour, so the most important factors are related to billet condition and initial properties of deformed metal, deformation history, elastic deflection and plastic deformation of tools and so on. Severe competition requires that fast and cost effective methods should take into account those factors. Numerical simulation of heat flow within tooling is potentially very useful. Such simulations could be carried out by means of various methods. Some of them would provide quite exact results of calculations on condition that exact descriptions of heat exchange coefficients and phenomena on workpiece-tool interface are available. However, it is very difficult to satisfy this condition without assuming some simplifications. For that reason experimental results on temperature distribution in cold and warm working tools have been very helpful in providing data for verification of numerical simulation. Findings of the application of IR thermography in studying phenomena in cold extrusion tooling were presented during TTP'96 conference [3].

2. Extrusion process and tooling

Warm forward extrusion of a rod was chosen for this investigation. It was designed for a crank press. The die insert was divided horizontally into two parts and prestressed radially by two prestressing rings. Die set was positioned by a sleeve. A heating device was mounted on the circumference of the sleeve to preheat tools up to 150°C before starting warm

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extrusion process. During heating, the punch was kept in the bottom dead centre. Workpieces of 20 mm in diameter were made of 0.1%C steel and lubricated by a graphite suspension in transformer oil. They were heated up to 750°C. The reduction of an extruded rod diameter was from 20 to 12.9 mm within a stroke of 17 mm to have only partial extrusion of the billet. Upper and lower plates of the tooling were connected by two pillars. Removals of the extruded workpieces have been carried out by means of a dedicated ejector driven by the upper plate [4].

3. Temperature measurement

Temperature measurements were executed using contact and non-contact methods. Internal temperatures were controlled by means of thermocouples. The used set of devices consisted of a thermostat, digital voltmeter, temperature regulator and contactor. In the case of the die Fe-CuNi thermocouple was placed between two parts of a split die insert. An additional thermocouple was placed inside the punch close to its face. Thermocouples have provided data on temperature changes at measuring points, only.

More extensive data on temperature distribution have been collected by means of IR Thermography (IRT) system. For effective using of IRT measurements, of special importance was to reduce the effects of the relatively low emissivity „ε" of the investigated surfaces as well as effects of movement of the die. Following to known metrological requirements (presented e.g. by Hamrelius [5]), care was directed for appropriate: fixing „ε" value's dispositions on the investigated surfaces, choosing of the IRT system, applying procedures of measurements and method of data processing.

Emissivity coefficients „ε" were experimentally established using known procedure of measuring reflections of the signals emitted by the blackbody type radiators. Used measurement formula, under some assumption can be written and derived as follows:

$$I_{meass.1} = I(T_{obj})\cdot\varepsilon + (I(T1_{BB}) + I(T_x))\cdot(1-\varepsilon);$$
$$I_{meass.2} = I(T_{obj})\cdot\varepsilon + (I(T2_{BB}) + I(T_x))\cdot(1-\varepsilon); \tag{1}$$

and after subtraction

$$\varepsilon = \frac{I_{meas1} - I_{meas2}}{I(T2_{BB}) - I(T1_{BB})} + 1 \tag{2}$$

where: $I_{meas\ 1}$, $I_{meas\ 2}$, - the radiation value (signal value proportional to the total radiation received integrated over the spectral response of thermal imager) obtained for reflection of the perfect blackbody radiation at the temperature T1, i.e. $I(T1_{BB})$, and at temperature T2, i.e. $I(T2_{BB})$, respectively.

It was assumed that T_{obj}, i.e temperature of the investigated surface of the object, and T_x, i.e. temperature of other sources in surroundings that are reflected in object (together with mentioned blackbody's radiation), can be unknown but should be constant during all the measuring procedure $I_{meas\ 1}$, $I_{meas\ 2}$.

Measurements were done having the surfaces seen in their spatial configuration with respact to the IR camera, like during the measuring task. Because of expected presence of the lubricating layer with different thickness, multiple tests of the „ε" were performed. The mean value of the emissivity coefficients for both the punch and circular type die surfaces were fixed using the same IR camera as for the main measuring task.

To lower potential errors as a function of emissivity variations over the object 3-5μm waveband camera was chosen. Because of short duration of measurements in this particular case it was possible to use the thermographic system consisted of old AGA680 camera but connected with CEDIP's modernisation kit. It consisted of: dedicated PC 12-bit PTR board for real time imaging and storing sequences of thermograms and PTRWIN software. It should be pointed out that, using of sequence of live thermograms stored directly in a digital form was

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especially important to fulfile requirements for steady state of spatial geometry of the measured surfaces and their surroundings.

IRT camera was situated on a tripod 1m far-away to the tool in such a way as to register temperature both on a punch surface as well as on a die surface. After having the camera calibrated, both digital and video films were recorded during extrusion of 38 workpieces.

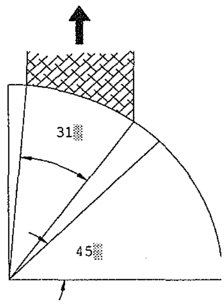

Fig. 1. Measured subsurface of the die the measured surface

All sequences of thermograms were processed using PTRWIN software. In the beginning only two thermograms (i.e. for billet and extruded product) were carefully chosen for being investigated in the same spatial position during all time of the experiment. In the case of die, five profiles were measured and averaged for part of the die surface as shown in Fig.1. Emissivity in the dashed part was reasonably uniform with mean value fixed to 0,32. Omitting the subsurface perpendicular to the IR camera direction together with using of carton screens helped to decrease and to stabilise the reflected signals form.

Similar procedures to stabilise influence of the surroundings were made in case of the punch.

3.1. Results of temperature measurements

Fig.2 presents temperature values indicated by thermocouples. As the number of extruded workpieces increases, the mean temperature of tool increases as well. Some drops in punch face temperature are related with longer cooling time after extrusion which was necessary to overcome some minor problems like alignment of a billet or periodic lubrication of the die. It is interesting to notice that die temperature stabilised at the level of 167°C after extrusion of 31 workpieces, i.e. about 6.5 minutes after starting the first extrusion.

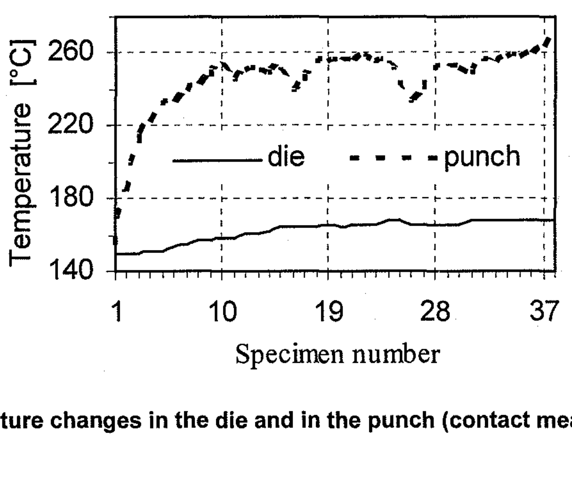

Fig. 2. Temperature changes in the die and in the punch (contact measurements)

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More detailed information on punch temperature distribution and temperature changes have been found by means of the thermographic technique, Fig.3. Maximum temperature variations on the punch face were within the range of 80-100°C whereas thermocouple measurements shown much smaller values. It is obvious that such difference is related with the delayed response of the thermocouple. On the other hand, changes in the mean temperature of punch face, during running subsequent extrusions, were comparable for both measuring techniques.

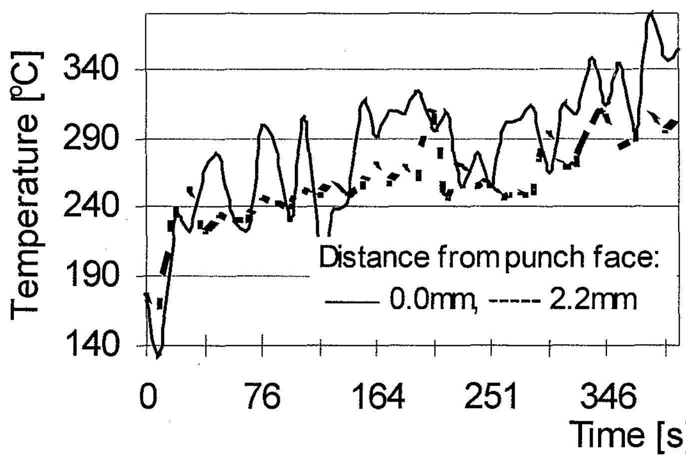

Fig. 3. Temperature variations on the punch face and its side surface (IR Thermography)

Figure 3 shows that this mean temperature was as high as 360°C at the end of extrusion of a series of workpieces. Mean temperature had been decreasing at the distances of 2.2 mm and 26 mm from the punch face down to 300°C and 125°C respectively. Temperature variations had become quite small at relatively small distance of 2.2 mm from punch face.

Generally, mean temperature of the punch face did not stabilised in the tested series of extrusions and would have been probably higher if extrusions could be continued. On the other hand, stabilisation of punch surface temperature has been observed quite early at some distance from punch face, e.g. after 150 seconds it was 200°C at the distance of 10 mm from punch face.

All the changes in punch surface temperature were examined in 3D diagrams, too. A preliminary heating of punch placed inside a die was clearly distinguished until the first extrusion started. Temperature of punch face increased quite fast at the beginning of extrusion of the first workpieces but temperature rise became much smaller with increasing a distance from the punch face.

4. Numerical simulation

Heat exchange in tooling during extrusion of a series of workpieces has been numerically simulated by means of FEM. As a result, temperature distribution in tooling was determined after specified number of extruded workpieces. Fig.4 shows temperature distribution on a cross section of tooling after extruding five workpieces.

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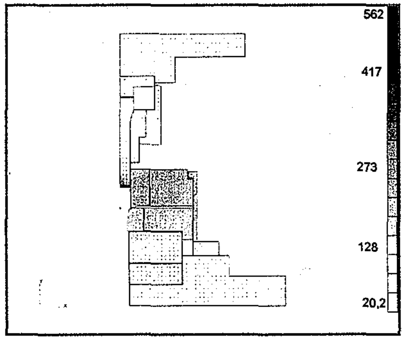

Fig. 4. Temperature distribution in (°C) on a cross section of tooling just after extruding fifth workpiece

Temperature values on the upper surface of die have been in a good agreement with temperature values found by thermographic technique. It is interesting to notice that maximum temperature of punch face was beyond 500°C just at the end of extrusion (punch in a lower dead point). After lifting the punch to its upper dead point, temperature had decreased to about 250°C, which was indicated by thermographic results as well. Then the variations in temperature of punch face had been even much higher than mentioned before, i.e. in the range of more than 250°C in one extrusion cycle. These temperature values and variations are quite important to be taken into consideration when selecting a tool material for warm working tools.

Temperature changes in warm working tool effect tool material properties to some extent. When analysing stress distribution in the tools, a constitutive equation (or just Young modulus in simplified considerations) as well as coefficient of thermal expansion of tool material should be a function of temperature. For example, Young modulus for a high speed steel used to make an extrusion punch changes from 210000 to 182000 MPa in the range of temperatures from 20 to 500°C respectively. Temperature dependent changes can be analysed as early as at the stage of preliminary treatment of a tool. A warm extrusion die is usually subjected to prestressing and preheating before starting an extrusion process. As in the case of this work, the die was preheated to 150°C.

Fig.5 shows an example of comparison of stress states analysed for different combinations of input data in FEM analysis, i.e. Young modulus E and α - coefficient of thermal expansion dependent (f(T)) or independent (const) of temperature T.

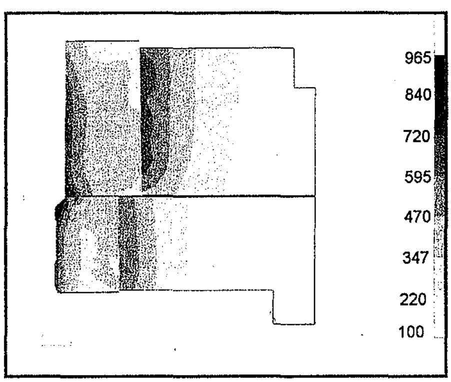

Fig. 5. Equivalent stress (MPa) distribution in the die subjected to prestressing and preheating for E=f(T), α=f(T)

http://dx.doi.org/10.21611/qirt.1998.038

Though temperature of die was changed only from 20 to 150°C due to preheating, calculated changes in equivalent stress had been remarkable (about 10%). Generally, stress values decrease when introducing dependence of E and α on temperature. Stress changes become quite high when temperature of tooling increases considerably because of extensive heat flow in warm working process. This effect is especially important when an exact analysis of tool deflection/deformation and its influence on accuracy of extruded product has to be carried out.

5. Conclusions

Application of the thermographic technique provided very useful additional extensive data on temperature distribution on surfaces of die and punch in various stages of warm extrusion process.

Experimental data and results of numerical simulation of heat exchange showed considerably high maximum value of temperature as well as wide range of cyclic changes of temperature in a punch, whereas a die was subjected to less severe thermal load. Temperature changes influence considerably stress state in a tooling.

6. Acknowledgement

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