Experimental Investigation and FE Modeling of the High Temperature Dynamic Properties of Metals in the Kolsky method

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1 Introduction

In a wide range of practical problem on the dynamic strength associated with the impact and penetration an adequate definition of the material properties as a strain rate and temperature function has a great importance. One of the most effective and reliable methods for determining materials properties at high strain rates is the Kolsky method using the split Hopkinson bar [1]. This method is based on the one-dimensional theory of elastic wave propagation and the assumption of homogeneity of strain in the sample. It allows to obtain the deformation diagram for the processes of compression and tension in the range of strain rates 200-10000 s-1.
Two basic schemes of the initial heating of the sample exist to study the materials properties at elevated temperature. In the one case, the heater is located directly on the axis of the rods (Fig.1) and heat-exposed not only the sample but also the adjacent parts of the rods.

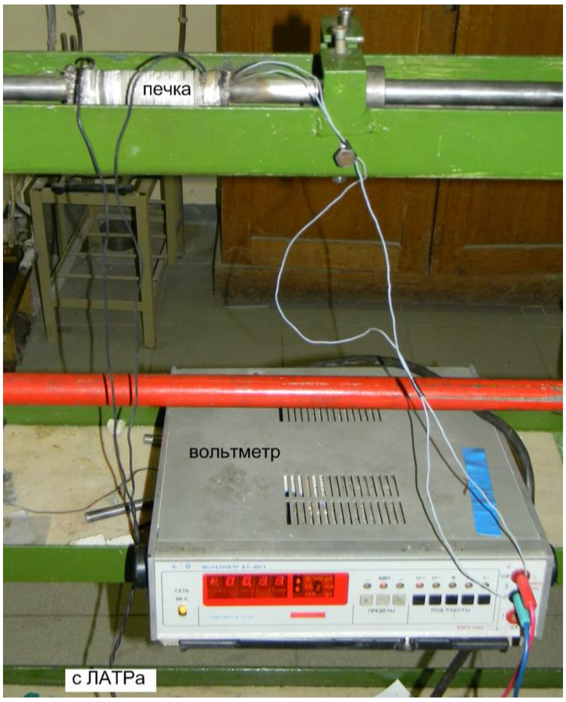


Fig. 1: Heater placed on the rods

In the second scheme, the furnace is at the distance from the rod (Fig. 2), heat is directly exposed to the sample. Thus, researcher should take into account a non-uniform temperature field produced by rapid cooling of the sample while delivering from the oven to the bars. In all cases it is necessary to clarify the standard scheme of the Kolsky method.

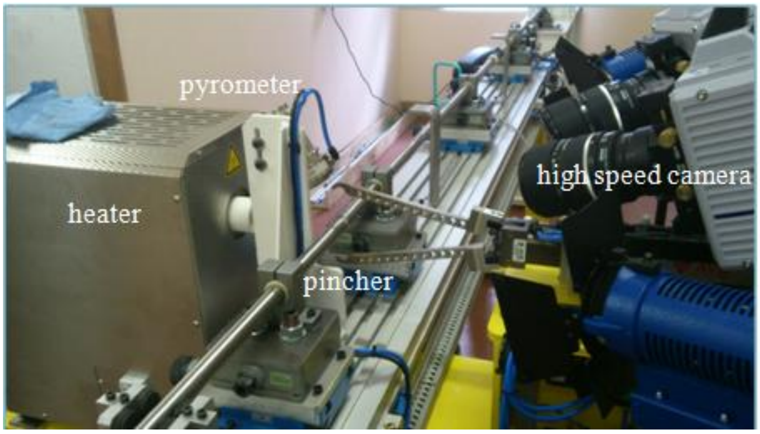


Fig. 2: Scheme with separate heater

The paper is concerned with a numerical and experimental investigation of the temperature and the stress-strain state in the specimen in compression tests with split Hopkinson bar with a remote oven. The goal was to determine the degree of heterogeneity of the temperature field in the sample during the test and to discuss the approaches to the refinement of a standard methodology.

2 Experimental temperature field investigation

The test with a split Hopkinson bar with a remote heater consists of the three main stage: initial quasi-static heating of the sample, then automatically placing the specimen between the rods and finally the actual test. In each stage we need to resolve the thermal (thermo mechanical) problem to define the stress-strain state of the sample (1)

$$\nabla \cdot k\nabla T + \dot{q} = \rho c \frac{\partial T}{\partial t} \tag{1}$$

Boundary conditions on the surface can be different types (2-6):
1. Set temperature

$$T\big|_{\Gamma} = T(x, y, z, t) \tag{2}$$

2. Isolated surface

$$\left.\frac{\partial T}{\partial n}\right|_{\Gamma} = 0 \tag{3}$$

3. Convection

$$q = h(T - T_{\infty}) \tag{4}$$

4. Radiation

$$Q = Af\sigma(T_1^4 - T_2^4) \tag{5}$$

5. Thermal contact

$$q = h_c(T_1 - T_2) \tag{6}$$

Actually such parameters as heat transfer coefficient *h,* interfacial conductance h_c and fracture of the radiation *f* are unknown values and depend on many factors like a surface temperature, roughness and color of the surface, contact pressure, boundary layer thickness, Reynolds and Nusselt numbers

etc. [2]. Some relations define the parameters in some simple cases but it is not enough for a common problem. Thus, experimental investigation is the only way for determining such characteristics.
The authors have performed a lot of thermal tests to obtain experimental data about boundary conditions. At the first stage on quasi-static heating a thermo metering along the pincher was done for different heater temperature (Fig.3).

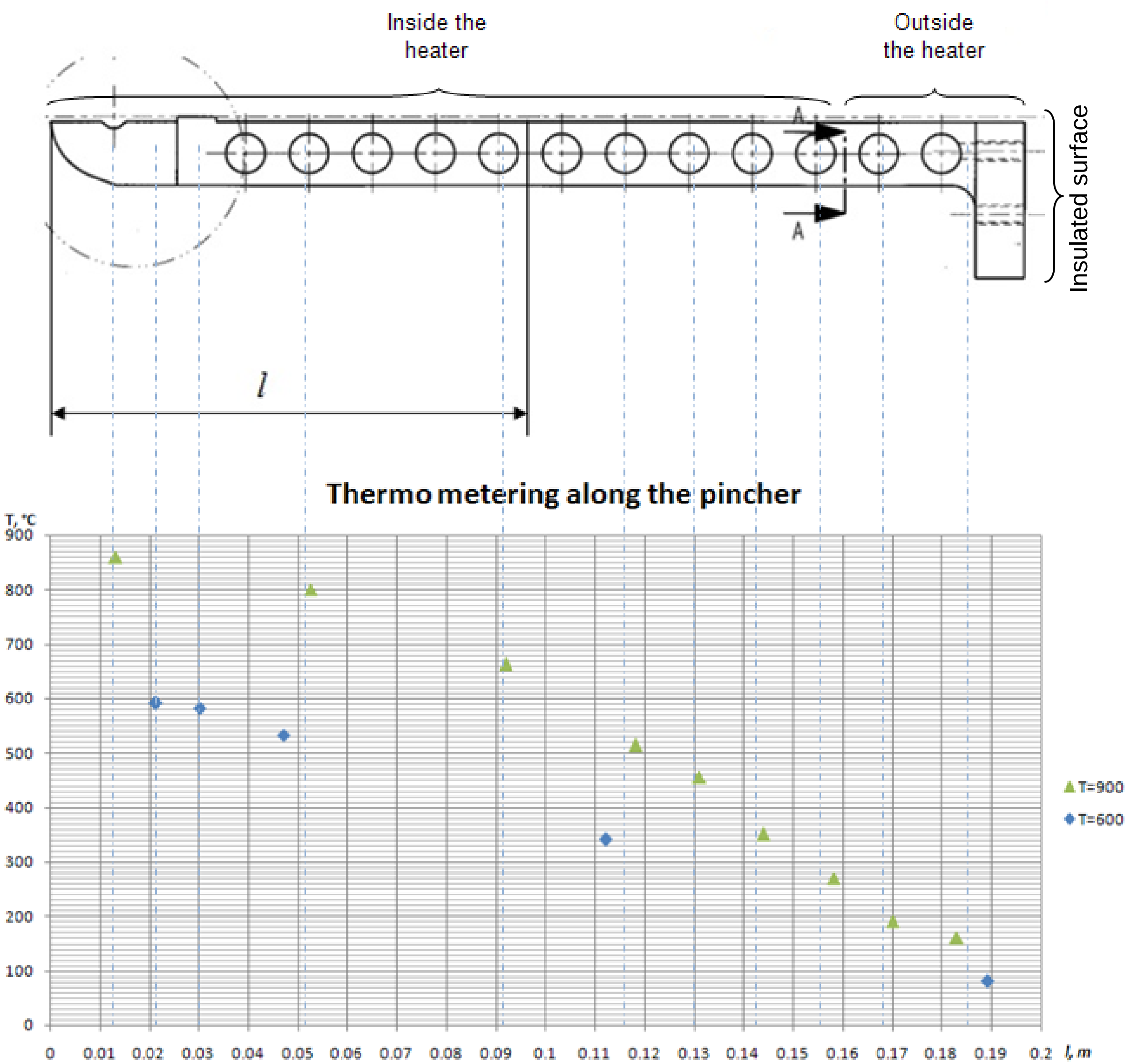


Fig. 3: Thermo metering along the pincher

It allowed defining the heat transfer coefficient of the pincher material (steel INOX 310s) as a function of temperature.
At the second stage as the pincher was moving from the heater the information from the pyrometer was obtained (Fig. 4). It is a type of an infrared sensor which was fixed over the working area. Thus, an experimental thermal data could be accepted during the dynamic test. It is important that in this case the boundary conditions on the pincher surface are time dependant.

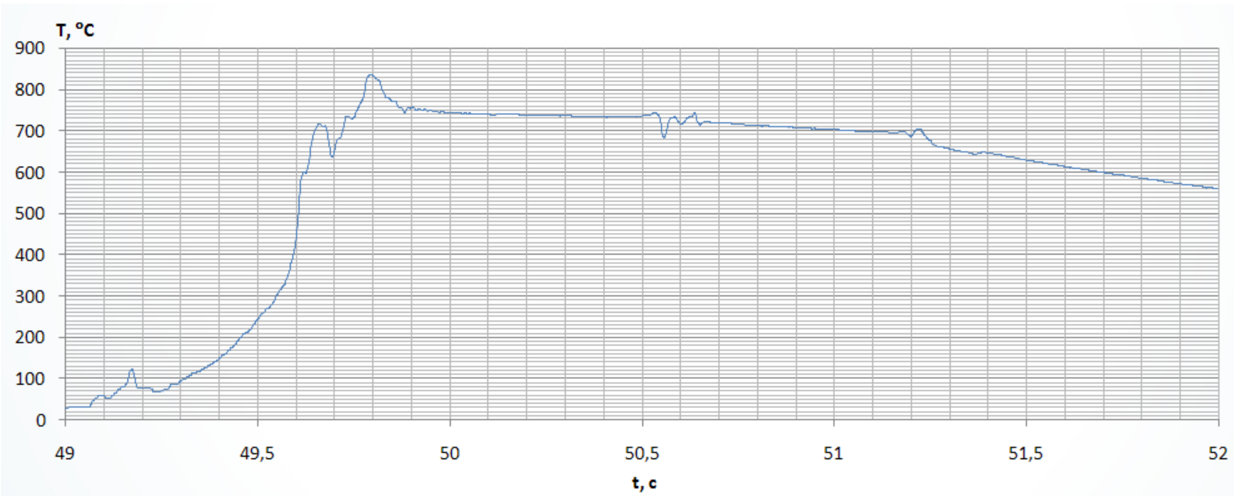


Fig. 4: Temperature measuring by a pyrometer

3 FE modeling of the thermal experiment

The quasi-static thermal stage was modeling in implicit way. The result is on the Fig. 5.

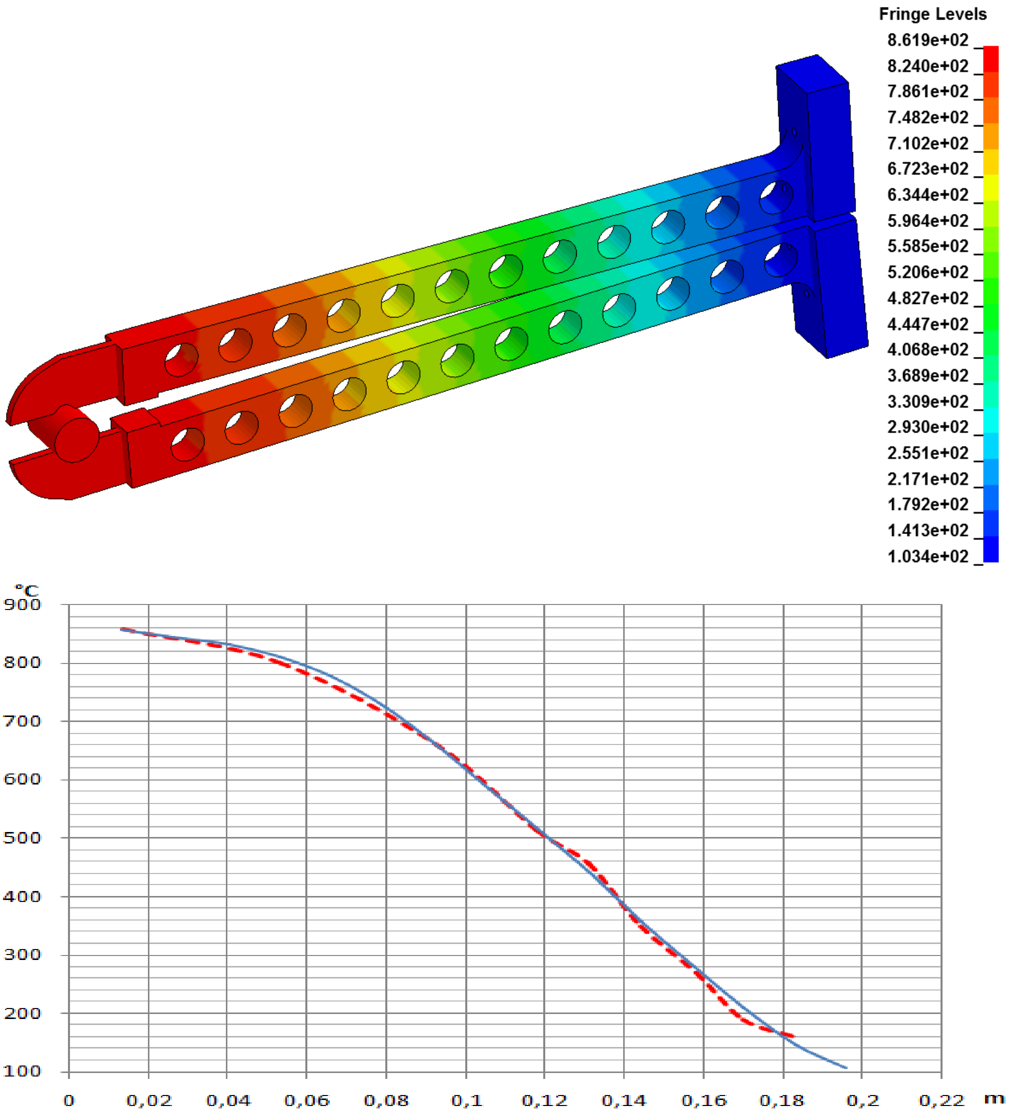


Fig. 5: Implicit modeling of the heating process

Standard material *MAT_ELASTIC_PLASTIC_THERMAL for steel pincher was chosen [3, 4] but also *MAT_THERMAL_ISOTROPIC_TD_LC was used to specify a temperature dependence of material properties. The card *BOUNDARY_CONVECTION_SET determined conditions at the different parts of the pincher in accordance with an ambient temperature. Curve for heat transfer coefficient is a result of validation numerical and experimental data (Fig. 6)

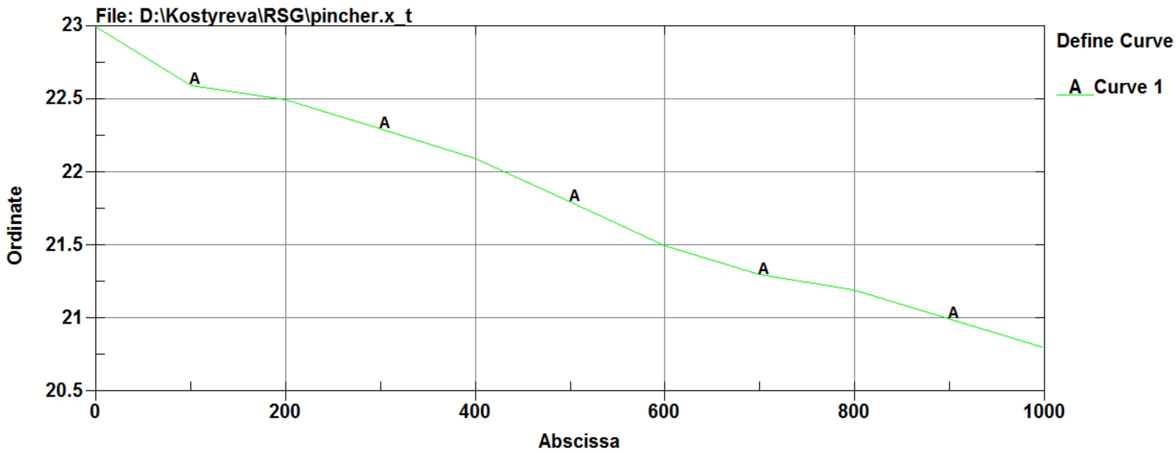


Fig. 6: Heat transfer coefficient under preheating.

Then transient analysis was performed with thermal body data obtained at the preview stage. Movement of the pincher was modeling through the time dependant boundary conditions. Actually the surface of the holder was divided into several segments of the same size. An ambient temperature for each segment was set as a piecewise constant function with time offset. Also due to the velocity of the holder is approximately 19 mps convection with air could be more intensive. Thereby the heat transfer coefficient should change (Fig. 7)

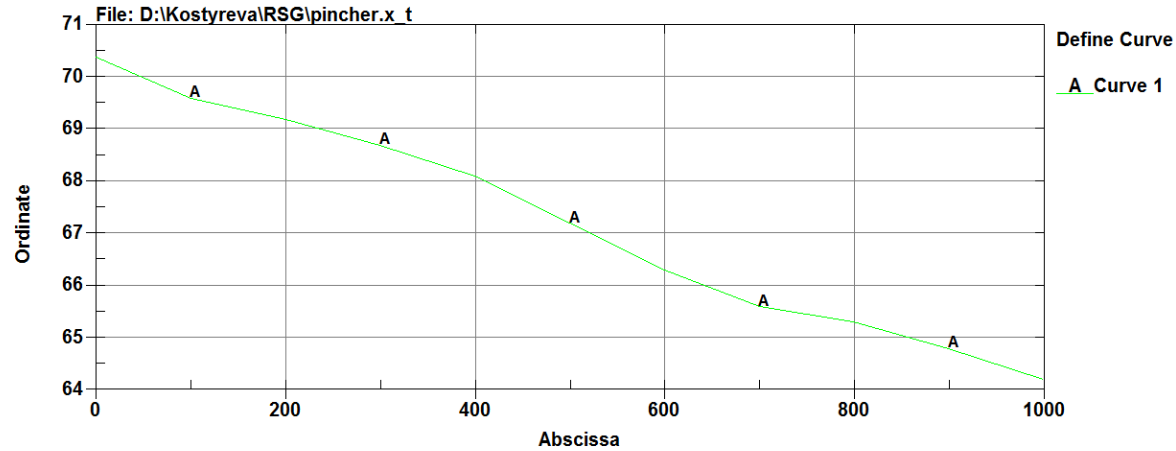
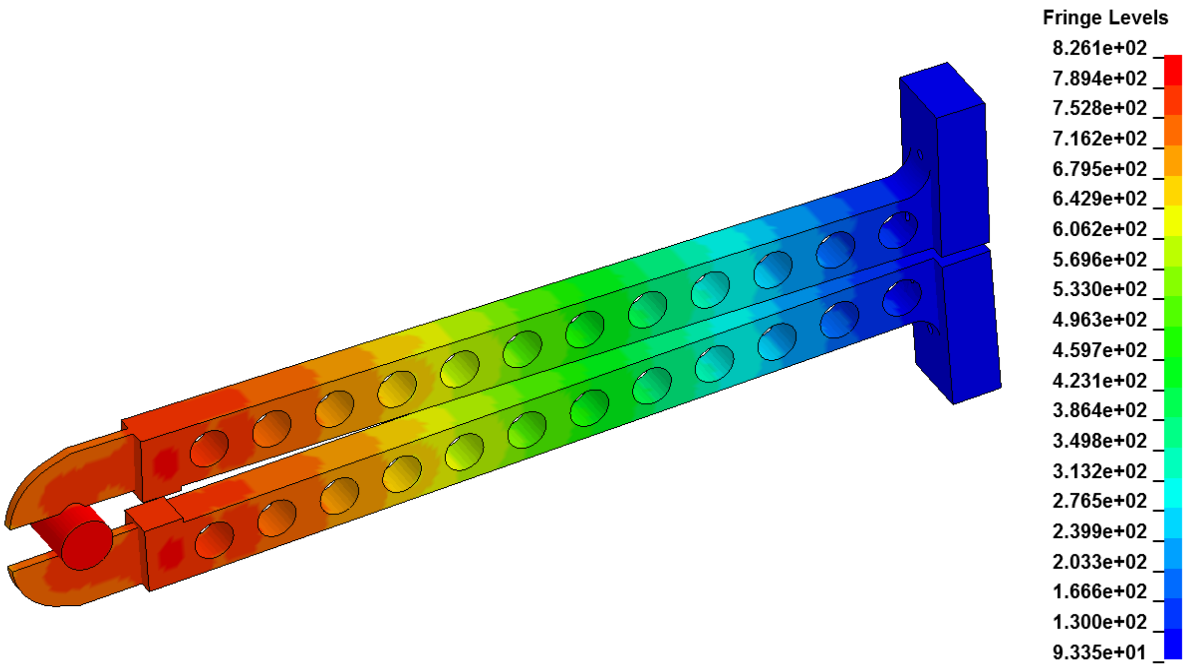
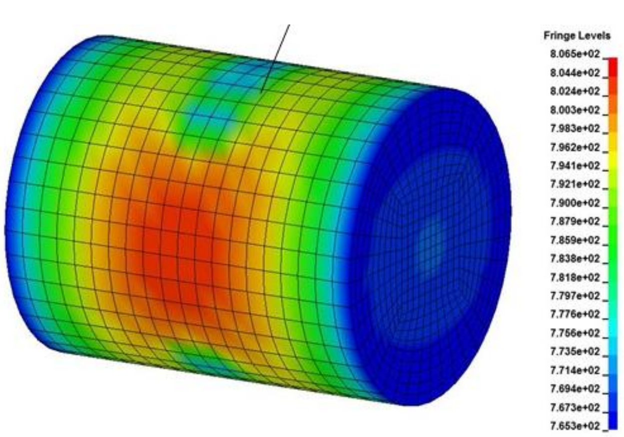
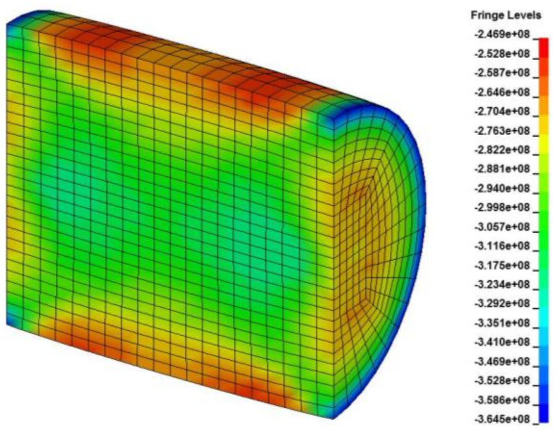


Fig. 7. Heat transfer coefficient during pincher movement.

The final stage is an actual test with split Hopkinson bar. Since the characteristic time of the experiment is a few milliseconds the main heat exchange is between specimen and bars due to contact and convection is insignificant. So it is very important to define an adequate interfacial conductance. At this time coupled thermal-mechanical problem was solved.
The results of the modeling is on the Fig. 8. Thus temperature variation in the sample achieve approximately 50 °C. It changes both in cross-section and along the sample. Hence it affects on the stress-strain state of the material.







4 Summary

The paper presents some results in FE modeling and experimental investigation of coupled thermal-mechanical problem. The temperature and stress-strain state of the sample and experimental equipment was defined. Since the main assumption about nonuniformity of the temperature field is confirmed then high temperature experimental test with split Hopkinson bar and remote heater ought to be clarify.
Thereby the authors propose to complete the standard Kolsky method by resolving thermal problem of preheating specimen mentioned above. It is also expected that the decrease in size of the sample would be beneficial for temperature field homogeneity.

5 Literature

[1] Bragov A., Lomunov A.: "Methodological aspects of studying dynamic material properties using the Kolsky method", Int. J. Impact. Engng. 1995. Vol.16, No2, p.321-330.
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