Serbian Tribology Society

SERBIATRIB '09

11th International Conference on Tribology

University of Belgrade Faculty of Mechanical Engineering

Belgrade, Serbia, 13 - 15 May 2009

THE THERMAL STRESSES OF FORGING DIE EVALUATION USING FEM

Stelian Paraschivoiu[1], Alexandru Pupăzescu[2], Cătălin Drumeanu[2], Ioan Tudor[2], Răzvan Ripeanu[2]
[1]UPETROM "1 Mai" Company, Ploiesti, Romania
[2]Faculty of Mechanical and Electrical Engineering, Petroleum-Gas University of Ploiesti, Romania

Abstract: *The forging dies (anvil tools) are subjected to thermal deteriorations. Their lifetime is strongly affected by thermal cyclical loads (thermal stresses and strains). A good analytical evaluation of gradient of temperature in the anvil body tool and, on the basis of these, of the thermal stresses map is very difficult. The new method for the calculation of stresses use the Finite Difference Methods (FDM) and Finite Element Method (FEM) for numerical solutions. The paper contains the evaluation of the gradient temperature and the stresses' distribution for the forging die for a work cycle using FEM. The values of the maximum of temperature and stresses are thus detected.*

Keywords: *thermal stress, forging die, FEM.*

1. INTRODUCTION

For the forging dies the effects of thermal cyclic loading consists in the plastic deformation of material, bleeding (maculate) of die surfaces, transformation of microstructures and initiation and propagation of cracks (fig. 1). Plastic deformation occurs when the stress on a die exceeds the yield strength at the operating temperature. Examples of a localized effect are rolling the corner of a punch or the initial yielding in a stress concentration prior to a fatigue failure.

Figure 1. The cracks in the body of die.

Low cycle fatigue occurs when a mechanical or thermal tensile stress is cyclically applied to a die during part production. Generally, the cracks appear in the separation area of the die at the beginning of the burr groove, where the temperatures are very high, about 900^o C, and at the internal connections of surfaces, were the mechanical and thermal stresses are high as well.

The level of thermal stresses due to closed die operations depends on the gradient of temperature, the thermal expansion coefficient and Poisson's ratio of steel. To reduce the level of thermal stresses is necessary to preheat the working surfaces of the die.

An accurate analytical assessment of temperature gradient in the body of die and on the basis of this an assessment of thermal stresses is very difficult to do.

The new methods, which are computer based, use the Finite Difference Method (FDM) and Finite Element Method (FEM) for numerical solutions. With FEM we can do thermal analysis for the following elements distribution of temperature, heat lost or gained, heat flux, thermal gradient. Based on this there can be two types of thermal analysis: steady-state thermal analysis and transient thermal analysis.

2. THE DISTRIBUTION OF TEMPERATURE FOR THE M60-1841 DIE

The analyzed die is made of two parts the upper and the bottom die (fig. 2). The upper die is equipped with a detachable punch (fig. 2).

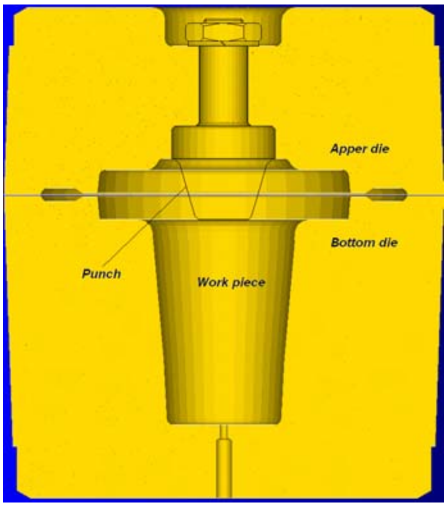

Figure 2. The geometry of M60-1841' die.

The steel of the two parts of die is 34MoCrNi16 having the following mechanical characteristics:
- Yield strength $R_{p0,2}$ = 700 MPa;
- Ultimate strength R_m = 900 ... 1100 MPa;
- Elongation at break A = 12%.

The operating parameters are:
- The temperature of the work piece at the beginning of the forging: T_b = 1180 ^oC;
- The temperature of the work piece at the end of the forging: T_e = 850 ^oC;
- Forging time: t_f = 50 sec;
- Rest time: t_i = 300 sec.

For the mechanical characteristics of die steel the following low temperatures (T in ^oC) are taken[4]:
- Modulus of elasticity [kN/mm^2]

$$E = 215{,}44 - 4{,}28 \cdot 10^{-2} T - 6{,}165 \cdot 10^{-5} T^2 ; \quad (1)$$

Thermal expansion coefficient [1/^{o}K]

$$\alpha = [10{,}22 + 5{,}26 \cdot 10^{-3} T - 2{,}5 \cdot 10^{-6} T^2] \cdot 10^{-6} ; \quad (2)$$

Thermal conductivity [W/m·K]

$$\lambda = 22{,}97 + 8{,}73 \cdot 10^{-3} T - 4{,}82 \cdot 10^{-6} T^2 ; \quad (3)$$

Specific heat [J/kg·K]

$$c = 433{,}33 + 0{,}4332 T - 7{,}4702 \cdot 10^{-4} T^2 + 8{,}0289 \cdot 10^{-7} T^3 . \quad (4)$$

3. THE MODELING OF THE DIE

The assessment of the temperature gradient in the body of die and on the basis of this, an assessment of thermal stresses was made with ANSYS 10. The two parts of the die are presented below in figures 3 and 4.

Because both parts of the die have an axis of symmetry, ax symmetric elements were used for modeling.

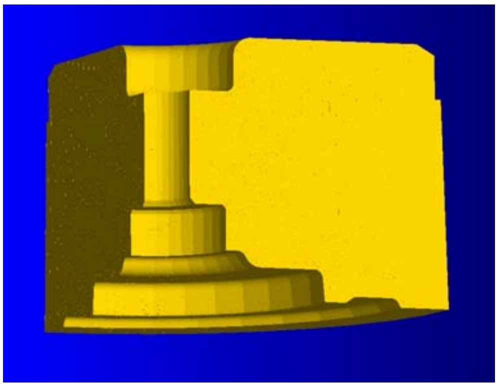

Figure 3. Upper part of M60-1841 die.

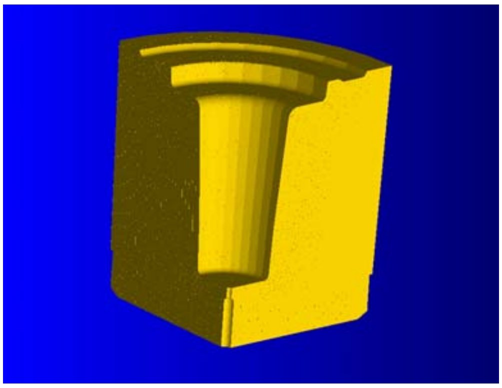

Figure 4. Bottom part of M60-1841 die.

The PLANE77 element was used for thermal analysis. The element has at each node one degree of freedom, temperature. The 8-node elements have compatible temperature shapes and are well suited to model curved boundaries. PLANE77 element is applicable to a 2-D, steady-state or transient thermal analysis. The element is defined by eight nodes and orthotropic material properties. A triangular-shaped element may be formed. Convection or heat flux (but not both) and radiation may be inputted as surface loads on the element's faces. Heat generation rates may be inputted as element body loads at the nodes.

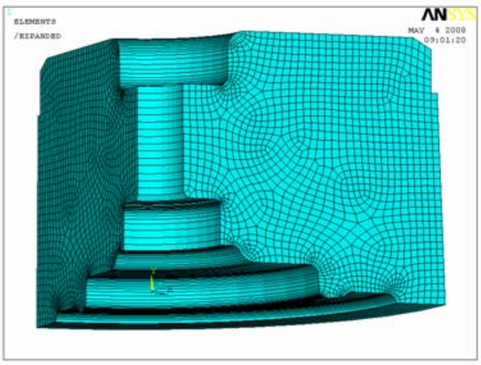

Figure 5. Upper die mesh (1/4 expansion).

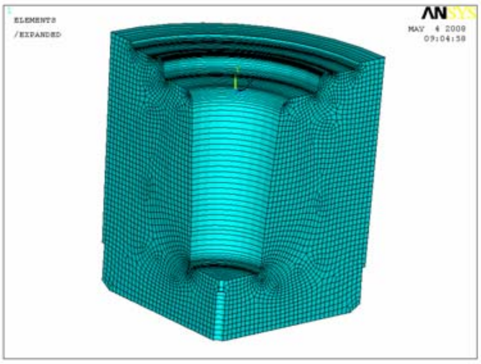

Figure 6. Bottom die mesh (1/4 expansion).

The meshes of models are presented in figures 5 and 6. These have 1456 elements with 4613 nodes for the upper die and 1713 elements with 5378 nodes for bottom die.

The same mesh was used for structural analysis with the PLANE82 element. PLANE82 is 8-node elements and have compatible displacement shapes and are well suited to model curved boundaries. The element is defined by eight nodes having two degrees of freedom at each node. Translations in the nodal *x* and *y* directions may be used as plane elements or as ax symmetric elements. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. The material properties are defined by Young's modulus, Poisson's coefficient and the thermal expansion coefficient.

The tensile curve of steel of dies was modeled according to the following relation:

$$\sigma = \begin{cases} E \cdot \varepsilon & \text{for } \varepsilon \le \varepsilon^e = R_{p0,2} / E \\ K \cdot \varepsilon^m & \text{for } \varepsilon > \varepsilon^e \end{cases} \tag{5}$$

In (5) ε^e represents the elastic strain; m – the hardening coefficient; K – the strength modulus.

For the calculation of m and K the below relation was used:

$$m = \frac{\ln(R_m / R_{p0,2})}{\ln[A/(0{,}002 + R_{p0,2}/E)]}, \tag{6}$$

$$K = R_m / A^m . \tag{7}$$

With the relation (5) ... (7), in soft, was introduced by the table the relation between the stress σ and the strain ε.

4. LOADS

Two heat transfer modes are considered, the convection with environment and conduction between the work pieces of die.

For the conduction, the calculation below has been used:

$$q_{cond} = \frac{Q}{At} = \frac{c\rho V \Delta T}{At} = 590{,}67 \cdot 10^3 \quad \text{J/m}^2\text{·s}. \tag{8}$$

where q_{conv} is the conduction heat transfer rate per area in J/m^2·s; Q is the heat transfer between work piece-die in J; A is the active area of the die in m^2; t - the operating time in seconds; ρ - the density in kg/m^3; V – the work piece volume in m^3.

For the convection, the following calculation was considered:

$$q_{conv} = h \cdot \Delta T = 4{,}651 \cdot 10^3 \text{ J/m}^2\text{s}. \tag{9}$$

where q_{conv} is the convection heat transfer rate per area in J/m^2·s; $h = 1{,}77 \cdot (\Delta T)^{\frac{1}{4}}$ is the heat transfer coefficient to the environment for vertical plate in J/m^2·s·grad [5]. Considering ΔT = 540^o C it results that h = 8,613 J/m^2·s·grad. To this a preheat temperature of the die of T_{ph} = 400^o C was also considered.

5. THE ANALYSIS

With these loads a thermal analysis for t = 50 s was done. The distributions of temperature at the end of forging are presented in figures 7 and 8.

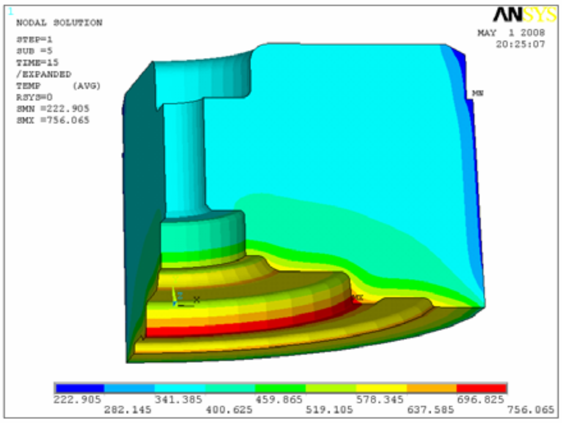

Figure 7. Temperature distribution at the end of forging in the upper die (^{o}C).

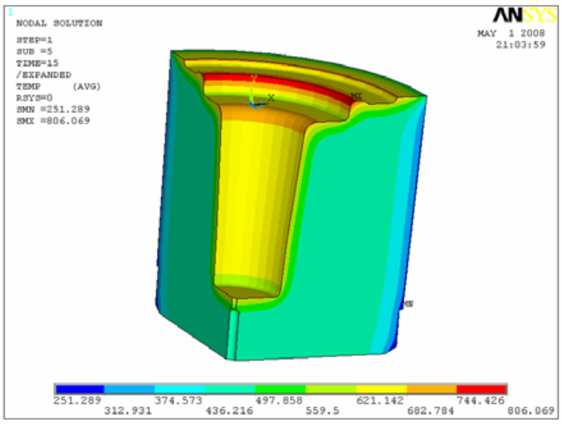

Figure 8. Temperature distribution at the end of forging in the bottom die (^{o}C).

The gradient of temperature was saved and was used for loads in the structural analysis. The maps of the Von Mises stresses are presented in figures 9 and 10.

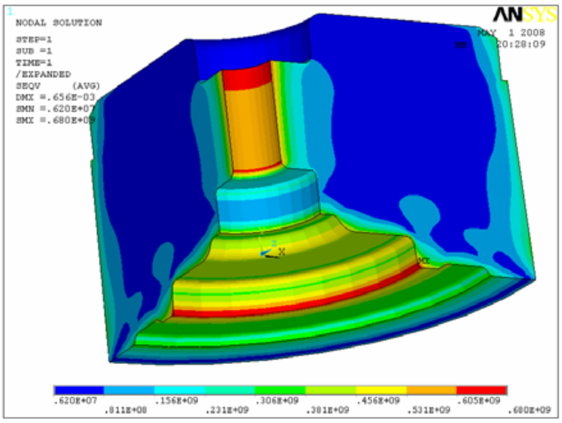

Figure 9. Von Mises stresses distribution in the upper die at the end of forging (MPa).

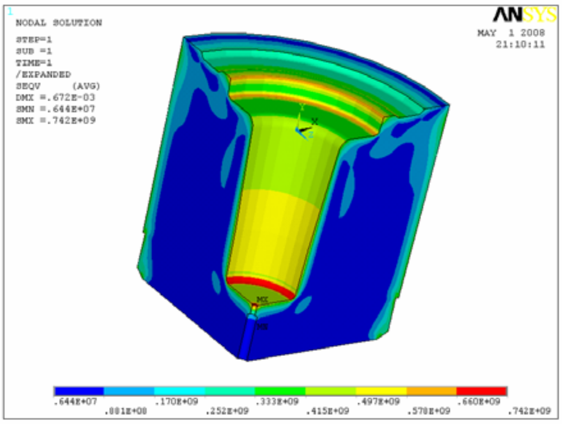

Figure 10. Von Mises stresses distribution in the bottom die at the end of forging (MPa).

For the distribution of temperature at the end of the rest the analysis was renewed taking into consideration then convection with the environment. The gradient of temperature is presented in figures 11 and 12 and the Von Mises stresses at the end of the interval t = 300 s are shown in figures 13 and 14.

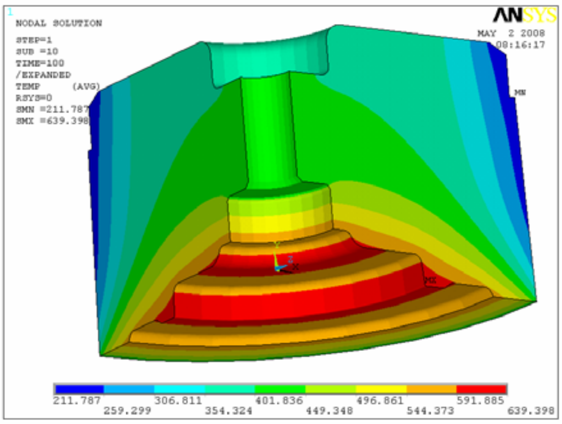

Figure 11. Temperature distribution in the upper die at the end of the rest (^{o}C).

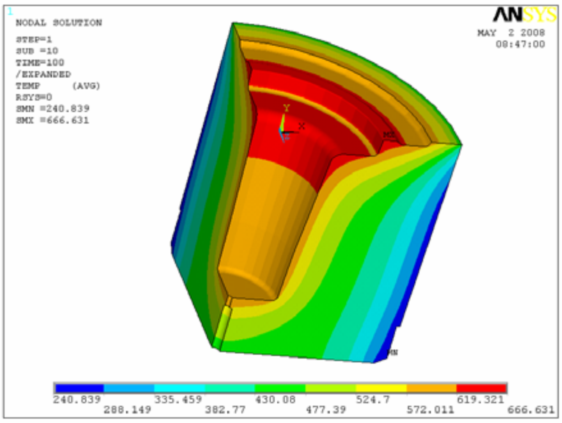

Figure 12. Temperature distribution in the bottom die at the end of the rest (^{o}C).

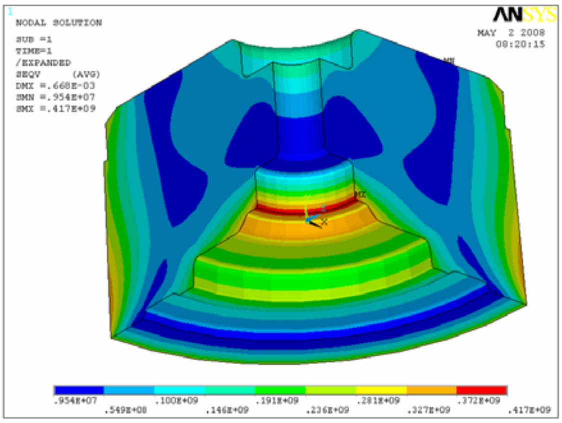

Figure 13. Von Mises stresses distribution in the upper die at the end of the rest (MPa).

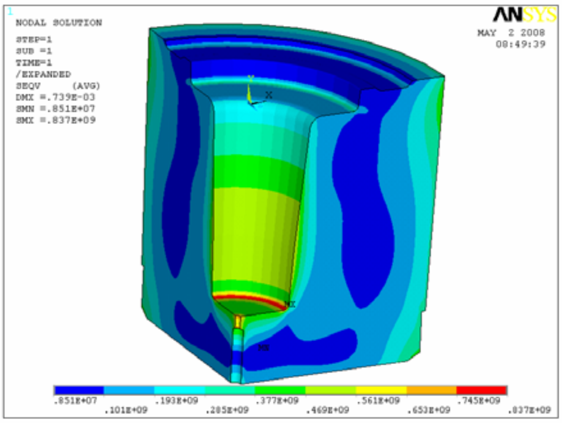

Figure 14. Mises stresses distribution in the bottom die at the end of the rest (MPa).

6. CONCLUSIONS

The highest thermal loading appears in the regions which are in contact with the work piece the longest. At that region of the die without or with only short contact to the work piece there is no significant temperature rise. The temperature in the bottom die is bigger than in the upper die. At the end of the forging process the maximum temperature is 756 ^{o}C for the upper die (fig. 7) and 806 ^{o}C for the bottom die (fig. 8). These temperatures are located at the beginning of the burr groove. The temperatures of the active areas vary between 578 ... 756 ^{o}C for the upper die and 621 ... 806 ^{o}C for the bottom die for forging and between 544 ... 639 ^{o}C for the upper die and 527 ... 666 ^{o}C for the rest.

The maximum equivalent thermal stresses which correspond to temperature distribution is located in the active area of the die. In the upper die the maximum equivalent thermal stress is 680 MPa (fig. 9) to forging and 417 MPa (fig. 13) to the rest. In the bottom die the maximum equivalent thermal stress is 742 MPa (fig. 10) to forging and 837 MPa (fig. 14) to the rest.

It is observed that, after the thermal regime is stabilized, the maximum thermal stresses vary between 417 ... 680 MPa for the upper die and 742 ... 837 MPa for the bottom die. The stresses are relatively high, exceeding sometimes the yield stress, but they are located at the work surfaces of the die and they represent the compressing stress. The thermal stresses and the mechanical stresses can determine the number of operating cycles and thus, the life time of the die.

REFERENCES

[1] [Chiriță, V., Drăgan, I., Maniu, Al., Vasiliu, A., *Matrițarea la cald a metalelor şi aliajelor*, Editura Tehnică, Bucureşti, 1979.

[2] * * * Release 10.0 Documentation for ANSYS.

[3] Popa, B., Bățagă, N., Mădărăşan, T., Adameşteanu, I., *Solicitări termice în construcția de maşini*, Editura Tehnică, Bucureşti, 1978.

[4] * * * EN 13445-3: 2002 Unfired pressure vessels - Part 3: Design.

[5] Sears, F.,W., Zemansky, M.,W., Young, H.,D., *Fizica*, Editura Didactică şi Pedagogică, Bucureşti, 1983.