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Heat transfer coefficient for F.E analysis in the warm forging process

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Analysis and modeling

ABSTRACT

Purpose: The Purpose of this paper is to obtain suitable convection and contact heat transfer coefficient for one-time finite element analysis in the warm forging process.

Design/methodology/approach: To do this, the temperature of the tool used in the operation was measured with a thermocouple and repeated finite element analysis(FEA) was performed using the experimentally calculated contact and cooling heat transfer coefficient. Also the surface temperature of the active tool was obtained by comparing the measurement and analysis results and finally the contact heat transfer coefficient for one-time FEA was completed by comparing the surface temperature between the repeated FEA and one-time FEA results.

Findings: The acceptable convection heat transfer coefficients are from 0.3 to 0.8N/mm/s/K and the contact heat transfer coefficient of 6~9N/mm/s/K is appropriate for the warm forging process with flow-type lubrication conditions.

Practical implications: A comparison of the temperatures from the repeated and one-time analysis allows an optimum contact heat transfer coefficient for the one time finite element analysis to be determined.

Originality/value: Several studies have been conducted with different conditions such as applied pressure and kind of lubricant, but no research has been conducted concerning the convection heat transfer coefficient in the warm forging process. Also, comparative analysis concerning the reason for difference between experimentally determined contact heat transfer coefficient and practically adapted one has not been conducted, yet.

Keywords: Numerical technique; Contact heat transfer coefficient; Convection heat transfer coefficient; Lubricant cooling

1. Introduction

In the metal forming processes, heat generation occurs due to plastic deformation energy. In the warm forging processes, heat generation and heat transfer form material to active tool greatly influences the service life of the tool. The main factors effecting tool life in the elevated temperature forging processes are wear, heat checking, fatigue, and plastic deformation [1-4]. The high temperatures of the active tool results in the forging processes like wear, adhesion between the materials and tools, and dimensional inaccuracy. Therefore, it is very important to predict temperature in the metal forming process.

To predict tool temperature, the contact heat transfer coefficient and convection heat transfer coefficient by lubricant are required. Several studies have been conducted with different pressures and lubricants, in order to predict the contact heat transfer coefficient between material and tool [5-6]. However, no research has been conducted concerning the convection heat transfer coefficient by lubricant yet. The contact heat transfer coefficients typically used are

11.5-30 N/s/m/°C [7-11]. However, these coefficients seem to be exaggerated when compared to those determined experimentally. Using a high contact heat transfer coefficient results in an acceptable tool temperature distribution in a one time finite element analysis.

The contact heat transfer coefficient for a one-time finite element analysis in the warm forging process was researched. The research consisted of the cooling tests, measuring the temperature of the active tools, and repeating the finite element analysis. The cooling test was used to calculate the convection heat transfer coefficient by lubricant. The temperatures of the active tools ware measured to determine their steady state temperature in a real operation. The thermo-mechanical finite element analysis was repeated using the experimentally calculated convection heat transfer coefficients and referred contact heat transfer coefficients until the temperature reached steady state conditions.

The coincidence of the steady state temperature between the measured and repeated analysis verifies the validity of convection and contact heat transfer coefficients. The surface temperature of a tool can be determined by repeated finite element analysis.

One-time finite element analyses using contact heat transfer coefficients from 8 to 11.5 N/s/m/°C by 0.5 N/s/m/°C increment were performed. By comparing the surface temperature between the repeated analysis and one-time analysis, the optimum contact heat transfer coefficient was determined.

2. Cooling test with lubricant

Cooling tests for H13 tool steel at 200, 400, and 600□ were conducted using the flowing lubricant, 25□ of emulsion Berulit625. Because most forging machines use the flow type cooling system, the lubricant was poured over the specimen surface. The specimen, designed as only on surface, was cooled by the lubricant and the outers ware air-cooled. Quenched and tempered H13 tool steel was used for the specimen. Figure 1 shows the shape of the specimen and the cooling boundary conditions.

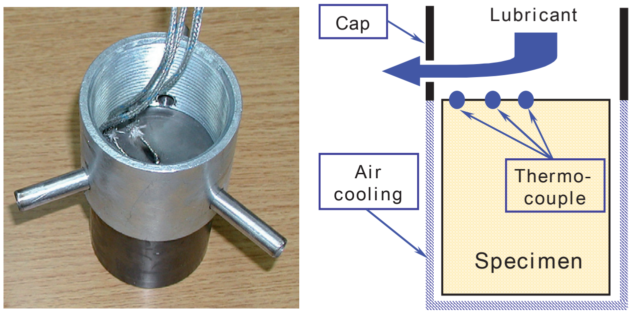

Fig. 1. Cooling specimen and boundary conditions

To increase the accuracy of the measurement, thermocouples were attached to three points. A uniform temperature of the specimen was achieved within five minutes of holding time in the chamber after the test temperature(200, 400 and 600°C) was reached. The lubricant was poured on the specimen and drained continuously. Figure 2 shows the temperature change for each cooling conditions.

3. Calculating the heat transfer coefficient

Convection heat transfer coefficients are not material property and have different values according to the boundary conditions. This coefficient can be calculated by the inverse method algorithm [13] using known mechanical properties and boundary conditions. Figure 3 shows the inverse method algorithm used to calculate the convection heat transfer coefficients. The inverse method algorithm requires temperature analysis and optimization. The temperature analysis was conducted by MPL [14], which was developed for thermo-mechanical plastic deformation analysis. The algorithm was optimized by the simplex method [15].

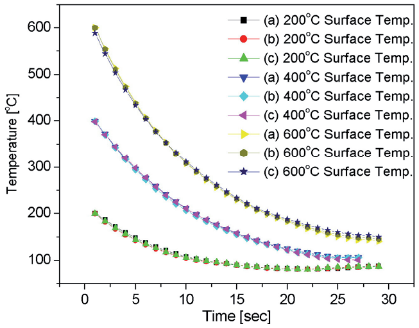

Fig. 2. Temperature distribution at points (a), (b) and (c) after being cooled with Berulit625 lubricant

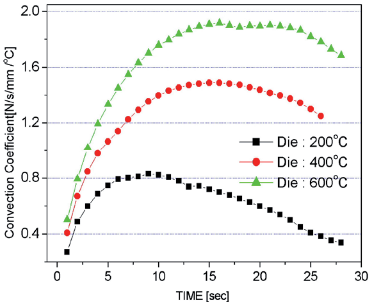

Fig. 3. The cooling heat transfer coefficients for different surface temperatures

The convection heat transfer coefficients calculated with the inverse method are shown in Fig. 3. As can be seen, the cooling rate is slow in the beginning. This is because a vapor film had formed on the surface of the part during the initial period of cooling. Because the vapor film has a large thermal resistance and heat conductivity is very poor, the exchange of heat flux between the workpiece and lubricant encounters resistance. Thus, the surface heat transfer coefficient is very small. As the cooling time increases, the vapor film steadily deteriorates and the exchange of heat flux between the workpiece and lubricant rapidly increases. Consequently, the convection heat transfer coefficient steadily increases [12]. A large number of differences in temperatures results in a high driving force in cooling capacity. Therefore, a higher heat transfer coefficient is expected. The initial convection heat transfer coefficients are 0.22, 0.31, and 0.45 N/s/m/°C for tool temperature of 200, 400, and 600°C as shown in Fig. 3.

4. Measuring tool temperature

The tool temperature of a rotor pole of the automotive alternator was measured. The warm forging process for the rotor pole consists of four stages. The second stage is lateral extrusion with a closed die. To decrease the tool temperature, in the second stage, an idle operation is performed after the forging operation. Because the lateral extrusion process requires severe load conditions, tool life is shortest. Therefore, tool temperature in the second stage was investigated. A thermocouple was welded to a corner after a corner after EDM at 2mm beneath the surface.

Figure 4 shows the temperature at 2mm beneath the surface of the tool. The steady state temperature of the tool during the forging operation was 98.3↑8C, the average value for 400sec.

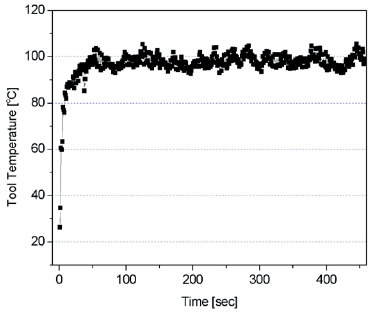

Fig. 4. The temperature of active tool measured

5. Repeated finite elements analysis

To verify the referred contact heat transfer coefficient and convection heat transfer coefficient by Berulit625 lubricant, a three dimensional thermo-mechanical finite element analysis was performed for the lateral extrusion process with DEFORM 3D. Forced cooling is described as a convection heat transfer coefficient of 0.46 N/s/m/°C calculated on the basis of cooling time. The contact heat transfer coefficient between material and tool are 2.5 N/s/m/°C for pressing operation and 1.5 N/s/m/↑8C for simple heat transfer operation, and were acquired form other studies [7,8].

The finite element analysis was repeated until the tool temperature reached the steady state condition. This occurred when temperature change was less than 2°C. Temperature was investigated at the same point where thermocouple was attached to measure tool temperature. Figure 5 shows the changes in the repeated finite element analysis with the history of the tool temperature.

The measured temperatures and the temperatures from the repeated finite element analysis are similar and compared in Fig. 6. This similarity suggests that the cooling and contact heat transfer coefficients are acceptable. With repeated analysis, the distribution of surface temperatures can be determined.

6. Steady state temperature calculation from repeated analysis

Optimum heat transfer coefficients can be calculated by comparing the nodal temperatures between the repeated analysis and one-time analysis. The validity of surface nodal temperature was verified by comparing the measured temperature and repeated analysis results.

With the analysis temperature history, the maximum and minimum steady state temperatures were calculated by the least square method and are listed in Table 1.

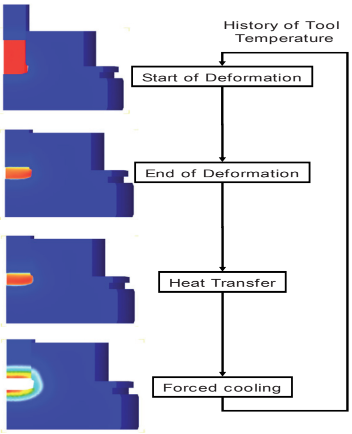

Fig. 5 Repeated finite element analysis flow with previous tool temperature history

Table 1.
Maximum and minimum steady-state at two points

Position	Point (a)	Point (b)
Min Temperature [°C]	181.1	147.3
Max Temperature [°C]	302.1	264.3

7. Optimum contact heat transfer coefficient

A one-time analysis was performed using a contact heat transfer coefficient from 8.0 to 11.5 N/s/m/□ by 0.5 N/s/m/□ increments and using the same conditions as the repeated finite element analysis. The analyzed temperature at points (a) and (b) with different heat transfer coefficients are listed in Table 2.

Figure 7 shows the distribution of the temperature for the one-time analysis by contact heat transfer coefficients at points (a) and (b) and the steady state temperature for the repeated analysis.

Acceptable contact heat transfer coefficient for each point can be calculated from the linear comparison of the one-time analysis and repeated analysis results.

As can be seen, an acceptable heat transfer coefficient for points (a) is 8.7 N/s/m/°C at point (b) is 5.8 N/s/m/°C. The difference of contact heat transfer coefficients is due to the effects of cooling, which are not considered in the one-time analysis.

Cooling effect of the lubricant is influenced by tool shape. Point (b) is in the corner, which can be easily cooled because of the two surface heat exchanges.

Table 2.
The temperatures at (a) and (b) point by heat transfer coefficients

Contact heat transfer coefficient [N/s/mm/℃]	Temperature at (a) position [°C]	Temperature at (b) position [°C]
Repeated analysis	302	264
8.0	290	313
9.0	310	348
10.0	325	364
11.0	340	391
11.5	348	401

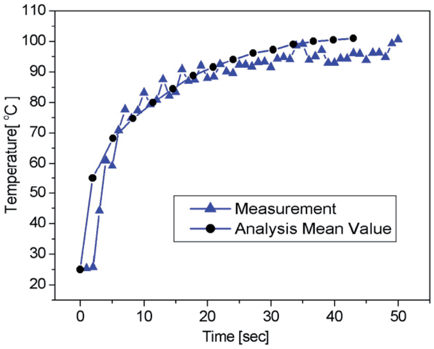

Fig. 6. Comparison of the measured and the finite element analysis temperature

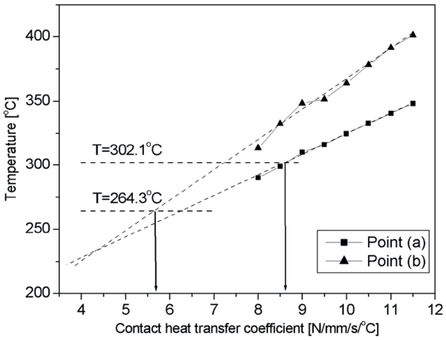

Fig. 7. Contact heat transfer coefficient calculation

8. Conclusions

An acceptable contact heat transfer coefficient between material and tool was determined by using the cooling test by lubricant, measuring the temperature of the tool, and completing the finite element analysis. A comparison of the temperatures from the repeated and one-time analysis allows an optimum contact heat transfer coefficient for the one time finite element analysis to be determined.

(1) The cooling test using a flow-type emulsion lubricant was performed, and the cooling heat transfer coefficients for tool temperatures of 200, 400, and 600□ and a lubricant temperature of 25□ was calculated by the inverse method. The acceptable convection heat transfer coefficients by lubricant in the forging process are from 0.3 to 0.8 N/s/m/□. The convection heat transfer coefficient can be changed according to tool temperature, lubricant temperature, cooling method, and cooling time.

(2) The contact heat transfer coefficients of 1.5 and 2.5 N/s/m/□ and the convection heat transfer coefficients of 0.46 N/s/m/□ with 2.432sec of cooling time shows good coincidence of temperature between measurement and repeated finite element analysis. Repeated analysis revealed that the maximum surface temperature reached about 300□.

(3) A comparison of the repeated and one-time finite element analysis results showed that the contact heat transfer coefficient of 6~9 N/s/m/□is appropriate for the warm forging process with flowing lubrication conditions.

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