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Improvement of Metal Forging Processes by Stresses and Temperatures Analysis

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HIGHLIGHTS

- The research discussed the causes of plastic deformation in dies.
- The temperature range employed in the forming process affected the quality of the analysis.
- The features gained in the hot forging process were determined and thoroughly studied.
- Development of hot forging tools and procedures.

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ABSTRACT

The mechanical components are produced by various fabrication methods, although forged products have excellent mechanical characteristics at a minimal cost. The stress and temperature analysis process in the closed die hot forging contributed to finding failure regions in these dies through simulations in the FE program. This enables the process to be improved and reduced time and mineral losses. A simplified model was used to represent the forming process, with a temperature of (1150-950 °C) was simulated using MSC Simufact software. The forge fastener head product is formed with a horizontal mechanical press of 800 tones. In this research, the workpiece material used Ck45 alloy steel, 56NiCrMoV 7 tool material. The results illustrate the maximum equivalent stresses values, and the maximum value was 739.70 MPa / 240.64 on lower die and product at a heating temperature of 950 °C, respectively. The local plastic deformation would be expected at places where the maximum stress is generated and exceeds the yield strength of the die material.

1. Introduction

The fastener head with variable cross-sections has been widely used in Cement production plants. A large quantity is required, so the hot forging close – die the best process. During the hot forging process, the dies are exposed to changes in the surface layer of tools caused by various failure mechanisms, including stress and temperatures. This study will focus on these two types of failure mechanisms by analysis to Improve hot metal forging processes. A first essential step in this direction is using tool steels such as 56NiCrMoV7 (DIN 1.2714) to withstand high mechanical loads and temperatures. Previous research literature included Jabbar, Mohammed S., et al. studied spring back in deep drawing process by comparison between the experimental and numerical simulation. The results show that elastic recovery decreased with increasing die wall angle, punch velocity, and sheet or blank thickness while increasing metal yielding stress. Also, the numerical simulation results show the same tendency and high agreement with experimental results with a maximum discrepancy of 4%. N. Biba et al. studied preform design to improve the method of hot forging. They created an isothermal surface method for forging preform design and found the A defect of the flow was removed on the interior surface of the flange, and the final blow load from 20 MN to 8 MN was decreased. F. Biglarib et al., the heat forging tool steel, studied the thermomechanical fatigue output of the Finite Element (FE) and developed a model. The principle of stress-strain hysteresis and elimination of elements was used to avoid failure. The results demonstrated two critical areas where maximum stress and temperatures will occur in the forging of the die, and the crack initiation and growth began from these critical areas. Hawryluk et al. For the study to wear a punch, the method of hot forging a punch-type cover component was chosen. In three operations, the procedure was performed using 18 MN crank presses. To ensure repeatability of operational performance, three instruments were used. Forging material (C45 steel – 1.0503), heated by about 11500 ^{0}C, and the instrument (WCLV heating steel - 1.2344, DIN – X40CrMoV5-1) to a temperature of about 11500 C.

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The findings showed that various wear mechanisms prevail in the same areas of the instruments. Gao, P. F., et al. studied the Die-Forging folding defect. This study designed an innovative thinking technique to estimate three conventional folds defect forms for forging die. The TA15 alloy was employed as the material research. The software FE models DEFORM-3D were used for three models developed. The AISI 1045 is the tool steel used to machine the dies. In a 20-ton press, the experiments were performed. The research methodology developed in this study, the versatile approach, has a wide range of applications in die forging for all three forms of folding. The folding index can also be used to minimize the probability of folded defects due to forging parameters optimization. Gronostajski, Zbigniew, et al. studied wear mechanisms by deposition of a hybrid layer on hot forging to improve tools' durability. The front-wheel forging test technique was chosen for testing. A crank press is used in forging metals. The raw material is 1150–1180°C at its initial temperature (forging Temperature). Three phases of operational testing were carried out, 1000, 2000, and 3000 forging pcs. The results showed differences in wear mechanisms in both evaluated layers and property changes in the surface layer before exploitation. Z. Gronostajski et al. studied the failure mechanisms that occur simultaneously on the surface of the dies. The research built a FEM model, MSC.MARC software provides a lot of forging conditions data. The tested temperature was: 750, 850, 1050, and 1250 ^{0}C. The research shows two networks of fine crack that occur in the forging process. The first one results from thermomechanical fatigue, the contact between the die and the forging, and the material flow rate, which typically leads to the establishment of a secondary network on the whole contact area. These failure mechanisms appear from the beginning of the process: plastic deformation, thermal cracking, and abrasive wear. Rajiev, R. The benefit of the forging method can be distinguished by good mechanical properties, optimum material use, a short processing period near-net form, and high productivity, which is usually accomplished in relatively large quantities due to high tool cost long production line set-up times. Pandya et al. The quality of the forging of the closed die depends on the configuration of the process, mold design, the flow of metal, the machine, etc. Aseel H. A. studied the effect of holding time on spring back theoretical and experimental. The results revealed that as the hold time increases, the spring back decreases, and the spring back ratio increases the value of sheet material in V-bending die. Gatea et al. optimize tools geometry in sheet metal forming U-bending to reduce the equivalent strain, equivalent stress, and thickness change after forming. The results show more uniform distributions in strain, stress, and thickness when using the same profile radius for die and punch (Bezier curve). This work examines the manufacturing process with a closed die, which affects one of the most critical sections of the fastener head under its working conditions, depending on temperature and stress caused by thermal and mechanical effects. Finite element simulation analyses of some important process parameters were used in MSC Simufact software to evaluate experiments to determine their impacts and form and analyze the practical results observed. This software uses the Von-Mises yielding criterion, the mostly used yielding isotropic function [12].

2. Experimental Works

The production process of the fastener head starts with closed-die hot forging with flash. Initially, the first cylindrical bar of AISI 1045 carbon steel with a base diameter of 30 mm was trimmed to 160 mm by a reciprocating iron saw to make 20 billets. The billets are divided into 5 groups of four pieces for each group heated by an electric furnace to a maximum temperature of 950-1150°C and compressed by a horizontal type 800-ton mechanical press. During the transfer of billets from the furnace to the mold, there was a decrease in the heating value of the piece by 5 °C. However, this decrease does not affect the properties—Figure 1 (a, b). To perform the experimental work, group number one heated to 1150 ^{0}C, group number two heated to 1100 ^{0}C, and group number three heated to 1050 ^{0}C. Next, group number four was heated to 1000 ^{0}C. Finally, group number five heated to 950 ^{0}C. After that, transfer to the horizontal mechanical press consist of punch and two parts of die upper and lower die, lower die fixed and upper die moveable down during forging stroke these dies made of 56NiCrMoV7 tool steel figure 2 (a, b). The chemical composition of low-alloy steel 56NiCrMoV 7 and workpiece AICI 1045 has been done as shown in table 1. This steel's mechanical and thermal properties are listed in Tables 2 and 3. Forging processes are under intense thermal conditions to decrease the production stress and improve the workpiece material's formability. The temperature of the billets and tools was measured by an infrared thermometer range (-32_1650 ^{0}C). Higher forging temperatures and pressures result in larger mechanical, thermal softening, and plastic deformation in the die forging process [13]. The production process of the fastener head was investigated with closed-die hot forging with flash. The processes took place in the State Company for Steel Industries.

Table 1: Chemical compositions for tool steel and workpiece

Material	C %	Si %	Mn %	P%	S%	Cr %	Mo %	Ni %	Co %	Cu %	AL %	V %	Fe %
Ck45	0.44	0.188	0.64	0.0036	0.0185	0.0296	0.0083	0.033	0.0182	0.062	0.0044	-	98.4
56NiCrMoV7	0.55	0.25	0.75	0.03	0.03	1	0.45	1.6	-	-	-	0.1	

Table 2: Physical and mechanical properties of AISI 1045 steel [14]

Properties	Metric Unit
Density	7870 (Kg/m3)
Yield Strength	310 (MPa)
Coefficient of Thermal Expansion	15 (µm/m. °C)
Poisson's Ratio	0.27
Hardening Temperature (Th)	760 (°C)
Melting Temperature (Tm)	1520 (°C)
Tempering Temperature (Tt)	400 (°C)

Table 3: Mechanical and thermal properties of 56NiCrMoV tool steel

Properties	Metric Unit
Modulus of elasticity [N/mm^2]	215000
Density [g/cm^3]	7.84
Thermal conductivity [W/m. K]	36.0
Electric resistivity [ohm mm^2/m]	0.30
Specific heat capacity [J/g. K]	0.46
Thermal expansion [$10^{-6}\,^{o}C^{-1}$]	14.6 between 200-700 ^{o}C

(a)

(b)

Figure 1: a) Billet dimensions b) electrical furnace

(a)

(b)

Figure 2: : a) Upper and lower die shape b) Horizantal mechanical press 800 T

3. FEM Simulation

The forging process of producing this part has been simulated in Axisymmetric three-dimensional form in MSC Simufact/v2019 software which uses FE simulations and FV simulations method. The boundary conditions of the process such as press speed, stroke, and the initial temperature of tools. The process parameters throughout the finite element simulation are applied as workpiece temperature.

Many researchers use the methodology for modeling the finite elements [15] to study the process of forging close die to form complex shapes amongst numerical approaches. Reliable business software for high-speed computing can be considered development and reliability as a primary reason for the FE procedure. The CAD software is suitable for using the FE simulation software (MSC Simufact) to model the component and die correctly. These models are imported into FEM applications for further processing. As actual treatments are performed at high temperatures, both deformation and thermal testing can be modeled by the solver used for analyzing the mold in the hot forging process.

The analyses of a hot closed-die forging are performed with the following process;

1) The forming process of billets
2) Simulation of die loads
3) Thermal die analysis

The Billet and die are 3-D modeling. The models are drawn in AutoCAD software and exported in “sat” format to MSC Simufact Forming. The upper and lower die dimensions with fixture as shown in figure 3.

4. Results

Each process was analyzed separately at all temperature ranges for experiments. The simulation was done at 1150 ^{0}C, 1100 ^{0}C, 1050 ^{0}C, 1000 ^{0}C, and 950 ^{0}C. The results obtained during the practical experiment were compared with the FE analysis in shape and dimensions, as illustrated in figure 4, table 4. Also, equivalent stresses and maximum principal stress distribution with temperature distribution on the upper and lower die are discussed in Figures 5 and 6 at all forging temperatures. Dimensions comparing (mm).

There is a clear convergence in the shape of the products between practical experiments and forming using the finite element program at all heating degrees of the workpiece. There are no defects, no fullness, and as shown in figure 4, the flashing of the products and the completion of the formation when the hot forging process is performed indicate that the metal flow pattern is also similar. In both cases, there is no need to add a preform stage. The dimensional comparison is illustrated to find out the discrepancy between the experimental and the analysis by FE, as shown in table 4. Also, the Equivalent Stresses analysis on the Upper and Lower die has been done, as shown in figure 5.

The above analysis for forging initial billet temperature showed that the Maximum Equivalent stress was at the upper die part and lower part at the edges. They are collected in table 5.

The stresses are among the reasons that lead to the failure of the molds due to the imposed loads with high temperatures. This causes the stress of the mold metal due to its exposure to thermal-mechanical fatigue and thus leads to failure. Therefore, the effective stresses (Equivalent stresses) were selected in the analysis process and their effect on the upper and lower molds and products, as shown in Table 5. The maximum Equivalent Stresses exceed the die yield strength, which is 380 MPa on the upper and lower die, and that means the local plastic deformation is expected to occur at these reigns. Also, the temperature distribution on the upper and lower die was analyzed, as shown in figure 6.

Temperature distribution on Upper and Lower die

The initial die temperature (preheating) was 250 °C. The temperature distribution increases in the forming regain at the edges of the die. The places where the temperature reaches its maximum values are where the workpiece is in touch longer than any other location. As we noticed, the temperatures increased in the upper and lower die during the forming process, especially in the area of the fastener head forming. The heating temperature of the billets was practically measured by a digital screen installed on the electrical furnace, and the temperature of the die was measured using an infrared thermometer.

Table 4: Maximum Equivalent Stresses Distribution on Lower - Upper Die and final product for all Billet Temperature

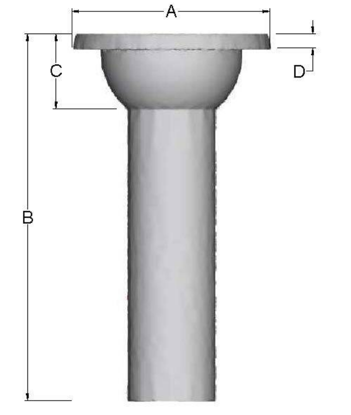
Max. Equivalent Stress (MPa)			
Billet temp. ºC	Upper die	Lower die	Billet
1150	507.66	543.46	140.24
1100	514.80	543.16	162.06
1050	618.32	630.65	183.37
1000	623.63	662.16	204.28
950	689.82	739.70	240.64

Table 5: Maximum temperature values on the Dies

Temperature maximum values for the dies (°C)					
Raw Material Temp.	1150 °C	1100 °C	1050 °C	1000 °C	950 °C
Upper Die Temp (°C)	346.86	357.21	379.32	392.23	400.30
Lower Die Temp (°C)	374.12	377.90	396.24	419.86	421.86

Table 6: Dimensions comparing between experimental and FE for all groups and at all temperature test

Temp. °C	Product	A	B	C	D
1150	1	50	140	23	4
	2	73	122	21	5.5
	3	63	130	22	5
	4	73	118	25	6
	mean	64.75	127.5	22.7	5.125
	FE	64.9	124.2	33.4	4.89
1100	1	48	140	25	5
	2	72	123	24	5.5
	3	73	120	27	6
	4	72	120	27	5
	mean	66.25	125.75	25.75	5.375
	FE	64.62	125.3	32.37	5.13
1050	1	50	140	25	5
	2	70	125	27	5
	3	73	122	27	5
	4	70	125	24	6
	mean	65.75	128	25.75	5.25
	FE	64.78	124.1	33.2	5.06
1000	1	50	140	26	5
	2	49	140	27	5
	3	70	122	24	6
	4	75	119	26	5
	mean	61	130.25	25.75	5.25
	FE	64.37	124.9	32.39	5.07
950	1	60	129	26	5
	2	47	141	23	5
	3	69	120	25	6
	4	70	122	28	5
	mean	61.5	128	25.5	5.25
	FE	64.65	124.2	30.39	5.05



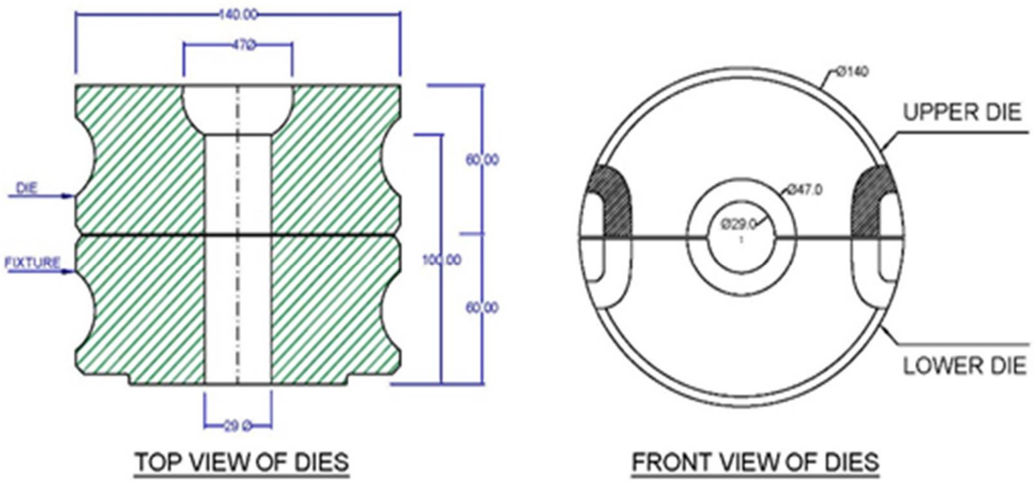
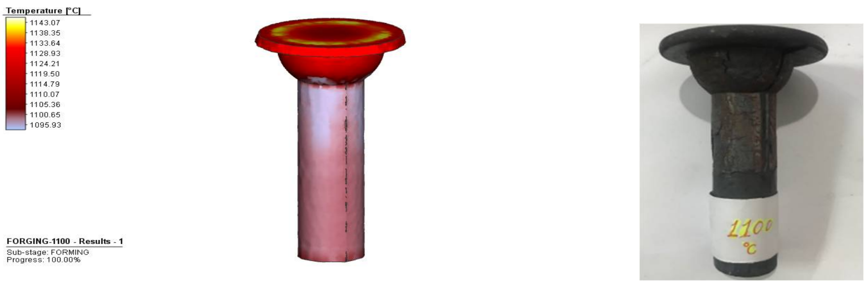


Figure 3: Dimensions of upper and lower die with fixture Compare shapes

(a)



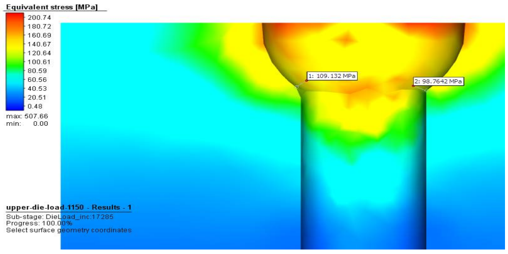
(b)

(c)

(d)

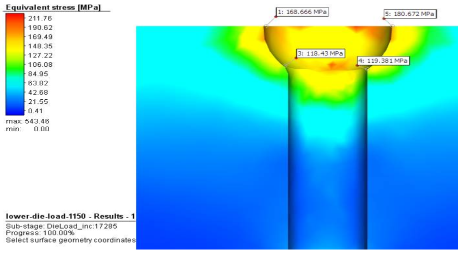
(e)

Figure 4: Experiment Result and Analysis at (a) 1150 ºC (b) 1100 ºC (c) 1050 ºC (d) 1000 ºC (e) 950 ºC



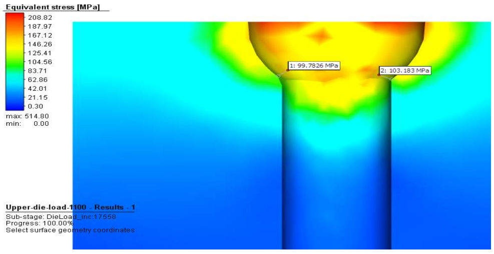
Billet Temp. of 1150 °C

(a)



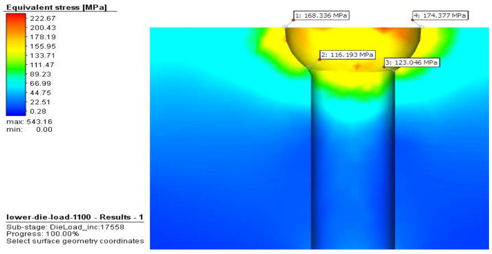
Billet Temp. of 1150 °C

(b)



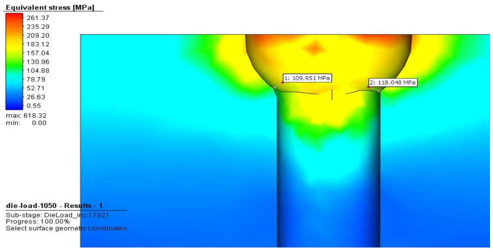
Billet Temp. of 1100 °C

(a)



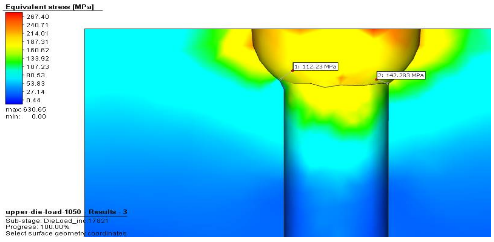
Billet Temp. of 1100 °C

(b)



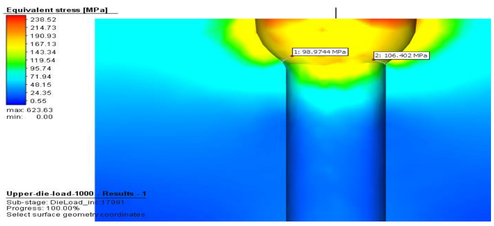
Billet Temp. of 1050 °C

(a)



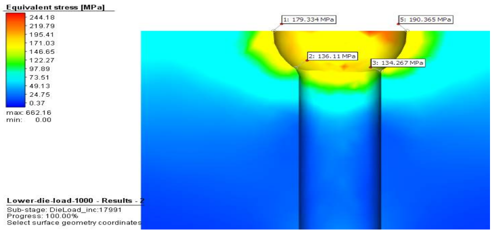
Billet Temp. of 1050 °C

(b)



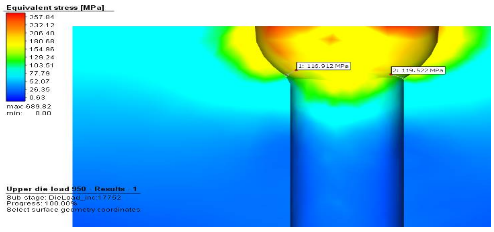
Billet Temp. of 1000 °C

(a)



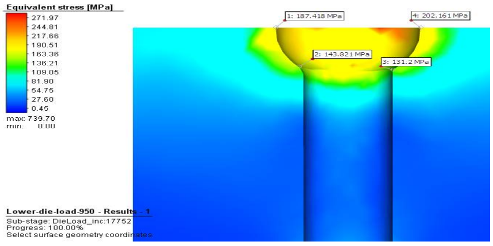
Billet Temp. of 1000 °C

(b)



Billet Temp. of 950 °C

(a)



Billet Temp. of 950 °C

(b)

Figure 5: Equivalent stress on (a) Upper Die and (b) Lower Die

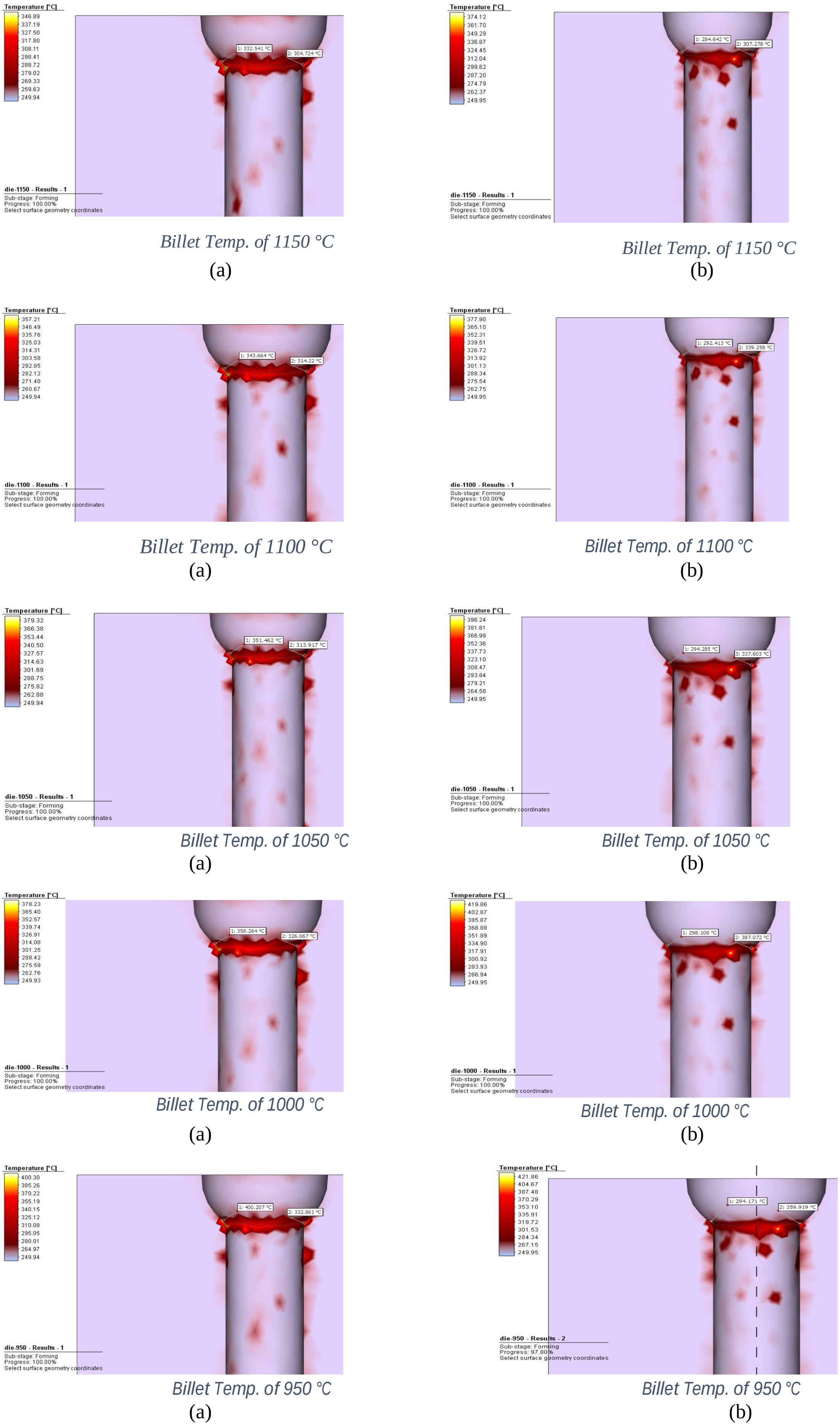


Figure 6: Temperature distribution on (a) Upper Die (b) Lower Die

5. Discussion

The results in Table 4 show a dimensional convergence between the average value of the number of products formed from the practical experience and the results obtained by using the finite elements. It was at a temperature of 1100 and represented by the symbol B. As for the head of the circular formation, represented by the symbol C, the greatest affinity occurred at the temperature of 950 ° C. The flash thickness is represented by the symbol D, where the closest convergence was at the temperature of 1000 ° C. This variance in dimensions between the actual results of the method's process and the expected values for the analysis of the specific elements depends on the complexity of the formation and cavity of the mold and whether the forming process is single-stage or multi-stage. It also refers to the position of the forged piece on the lower die, and this varies at each cycle of hammering according to the experience of the production operator. (B) And reduce the diameter of the flash for it (A). Also, the equivalent stresses are aggregated and distributed over the entire forming area, as shown in yellow color. They also increase more around the edges and ends of the molds, especially at the flash formation area at the punching area. This, in turn, causes permanent deformations of the molds and may result in a large number of damaged and hot work tools in the forging operations. This indicates that the equivalent stresses values has exceeded the yield point of the die metal. So, designing the tools and choosing the die metal must ensure that the equivalent stress does not exceed the yield stress. As we can see from table 5, the equivalent stresses are higher in the lower mold than in the upper die. The great value of the maximum equivalent stresses was 739.70 MPa / 240.64 on the lower die and product at a heating temperature of 950 °C, respectively. Because the lower die is more in contact with the heated piece is more susceptible to high temperatures, and the areas that are in longer contact with the forged material are more severe for the wear than others, and this happens by increasing the number of forgings and when the metal " fatigue ".

6. Conclusions

1 The FEM is the reliable analytical model for showing the stresses contrition and temperatures distribution on close-die forging.
2 The experiment results in the hot forging process and (FE) simulation were achieved at all forging temperatures, and they were converging.
3 Dies stresses decrease as the heating of the initial billet temperature increases.
4 Dies temperature increased as the heating of the workpiece decreased.
5 The analysis helped discover weaknesses in the template design process as stresses were concentrated in the edge areas. As a result, the maximum equivalent stresses values are greater than the die material's yield strength. For example, the great value of the maximum equivalent stresses was 739.70 MPa / 240.64 on lower die and product at a heating temperature of 950 °C, respectively.
6 These findings demonstrate that local plastic deformation is expected in upper and lower dies.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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