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Cıvata soğuk dövme işleminde kalıp ömrünün arttırılması: dövme kademe tasarımının etkisi

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ÖZ

Bu çalışmada özel M10x32 dog-point cıvataların soğuk dövme işleminde meydana gelen kalıp hasarı Simufact.forming sonlu elemanlar simülasyon programı kullanılarak incelenmiş ve dövme kademe tasarımlarında değişimler yapılarak kalıplar üzerinde meydana gelen yüksek gerilme değerlerinin azaltılması amaçlanmıştır. Çalışmanın ilk kısmında cıvataya ait beş farklı dövme kademesinde meydana gelen malzeme akışı modellenerek belirlenmiş, kalıp kırılmasının yaşandığı dövme kademesinde oluşan kontak basınçları ile kalıp gerilmeleri tespit edilmiştir. Simülasyonlar cıvata kafa ve flanş kısmının dog-point'in oluşturulduğu dövme kademesinde aynı anda şekillendirilmesi nedeniyle sabit kalıp üzerinde yüksek çekme gerilmesinin oluştuğunu ve kalıbın bu nedenle hasara uğradığını tespit etmiştir. Bu durumu engellemek amacıyla dog-point kısmı bir sonraki dövme kademesine alınmış ve hazırlık açısı 40°'ye düşürülmüştür. Buna ek olarak tek parça olan dövme kalıbı tasarımı iki parçalı tasarım ile değiştirilmiştir. Bu tasarımlar ile gerçekleştirilen simülasyonlar dövme kalıbındaki gerilmenin yaklaşık %70 oranında azaldığını göstermiştir. Son olarak yenilenen kalıplar ile yapılan üretim denemelerinde kalıp ömrünün 3.8 kat arttığı görülmüştür.

Anahtar Kelimeler: Soğuk dövme, cıvata, simülasyon, kalıp, hasar

Tool life enhacement in cold bolt forging process: effect of forging stage design

ABSTRACT

In this paper, tool failure evolution in cold forging process of special M10x32 dog-point bolts was investigated with Simufact.forming finite element software. In the first part of the study, material flow in the five different forging stages were modeled and contact and tool stresses were determined. Simulations revealed that simultaneous forming of the flange, head and socket of the bolt with dog-point section causes excessive tensile stress evolution on the stationary die which leads to tool fracture. To prevent the failure, forming of dog-point section was shifted to further forging stage and preparation angle for dog-point was decreased to 40°. In addition, monolithic tool design was replaced with split insert design. Simulations carried out with these designs showed that tool stress was decreased about 70%. Finally, forging trials were also conducted with the updated tools and tool life was seen to increase about 3.8 times.

Keywords: Cold forging, bolt, simulation, tool, failure

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1. INTRODUCTION

Cold forging is a metal forming process which enables high speed mass production with great mechanical properties. Leading automobile companies starts to prefer complex forged parts for their superior mechanical properties over cast and machined parts [1]. This forces forging companies to decrease production costs. Due to increasing geometrical complexity of the parts, forging tools (dies) are exposed to excessive forming loads which negatively affects service life of tools. Strain hardening of workpiece material, extreme friction conditions, high strain rates and poor lubrication are also triggers of tool failure. In cold forging tools, main failure mechanisms can be listed as; i) plastic deformation, ii) wear and iii) fatigue [2, 3]. In cold forging process, dies and punches are subjected to compressive stresses up to 2000 MPa that may lead plastic deformations like chipping and local fractures. In some cases, complete bending of a punch may happen. For these reasons, high compressive strength and hardness are required for tool materials [4]. Wear is the loss of the material from the parts that are in contact due to excessive friction under high normal stress. In metal forming operations, wear has a great influence on tool life, dimensional accuracy and surface quality of products [5]. Dynamic and repeated forging of workpiece material causes cycling loading on forging dies and it may lead crack initiation and early fracture of the die which is classified as fatigue failure [6]. More information about failure of dies and molds can be found in the review paper of Jhavar, Paul and Jain [7]. Tool life has significant impact on forging cost in fastener production. As cold forging tool costs cover 10% for standard and 40% for special bolts of total production cost, it is crucial to improve tool life to increase competitiveness of the company. It is also important to decrease inactive time of the forging press due to replacing of failed dies, labor efforts and energy. At this point, quick application of finite element simulations of metal forging operations becomes very valuable in order to make design modifications to increase the effectiveness of the dies. In metal forming industry, researches were mainly focused on numerical modeling of forming processes. Simulations has been used in German and American forging industry since 1980s [8]. Industrial and scientific applications of metal forming simulations grew with the development of commercial finite element softwares in 1990s. Metal forming simulation softwares like Simufact.forming, SFTC Deform, Forge NxT and Qform are leading examples. By the help of these softwares, stress distribution can be determined on tools and results of critical design modifications can be obtained without conducting any trial-error studies in the production. In the literature, studies are mainly focused on tool life estimation, effects of die surface modifications to improve tool life, failure mechanisms and shrink fitting effects on the tool stresses. Geiger et al. [9] investigated Von-mises stress distribution in extrusion process and they used numerical results to obtain optimum die shoulder geometry. It was concluded that Von-mises stress on the die was reduced to 1050 MPa from 1535 MPa with the usage of optimum radius value in extrusion die. Berns et al. [10] determined the critical stress area on dies in the process of screw forging. Particle distribution in metal matrix of forging die was then optimized by using microscale simulations to get highest cracking resistance. Double dispersed tool material was found to be 30% higher fracture toughness in contrast to single dispersion material. Vazquez et al. [11] revealed the potential of different methods to improve tool life in cold forging. Usage of tougher insert material, increasing shrink fit ratio and splitting insert from the locations where the maximum principle stress is highest were determined to be very effective on tool life enhancement. Engel and Popp [12] applied excimer laser to surface of cold forging die to form microtextures. It was found that microtextures provide extra space for lubrication in contrast to polished surfaces and the tool life was increased up to 300%. Lee et al. [13] investigated the effect of shrink fitting ratios on the effective stress generated on cold forging dies in the process of hexagonal bolt and gear forming. Optimum shrink fitting ratios were 0.52 and 0.75% for first two bolt forging stages and 0.33% for gear forging. It was also concluded that appropriate shrink fitting ratio should be determined for each operation to get high cycle fatigue tool life. Andreas et al. [4] investigated the effects of surface finishing operation on tribological properties of G55 cemented carbide. After EDM (Electric discharge machining), tool surface was shot peened and polished with diamond grits having 15 μm (D15), 9 μm (D9), 6 μm (D6) and 1 μm (D1). It was determined that polishing up to D6 leads to reduce friction factor to 0.03 while polishing with D1 does not have any influence on friction factor. It is also important to note that decrease in surface roughness may cause to reduce oil retaining ability of the surface which results an increase in friction. Ku and Kang [1] modeled the multi-stage cold forging process of steel outer race of BJ-type CV joint and determined the tool stresses. Experimental application of the process revealed that part was well formed with desired dimensions without experiencing any tool failure. It was concluded that results of the numerical simulation was very applicable. Ku and Kang [14] used numerical forming simulations to investigate flow of inner race with ball grove parts. Tool failure was detected after forging of 15 parts. Tool stress analysis were carried out with Deform software and tool modification, increasing tool fillet radius from 1 to 100 mm, was seen to decrease tool stress about 70%. Yurtdaş et al. [15] revealed the potential usage of carbon fiber reinforced composite tubes as stress rings in cold forging dies. Study showed that shrink fitting ratio can be increased up to 3.5% with carbon fiber composites while conventional tool steel stress rings allows maximum 0.7% shrink fitting ratios.

In this paper, multi-stage cold forging process of special M10x32 dog-point bolts was investigated numerically to reveal the reasons of tool failure occurred in fourth forging stage of the operation. Forging simulations and tool analyses were carried out in Simufact.forming finite element software. Material flow in the five different forging stages, contact and tool stresses were determined. Modifications were made in die geometry and forming simulations were repeated to reduce tool stresses.

2. COLD FORGING PROCESS AND TOOL FAILURE

M10x32 dog-point bolts were forged from annealed DIN 1.5536 steel alloy on a forging press having maximum capacity of 1395 kN (140 tones) in Norm Fasteners Co./Turkey. Forging stages and final bolt geometry before threading process (Stage 5) are shown in Figure 1. The bolt is forged to desired geometry and dimensions through using five forging stages. The process begins with the shearing of the work-piece material from a continuous bar. Work-piece is then transferred to stage 1 by grippers. Top die pushes the work-piece and forces it to flow through stationary die cavity. After finishing the forming stroke, ejector pushes the formed part and throw it through the outside of the die. Grippers again hold the formed part and transfer it to the next forging stage. As shown in Figure 1, extrusion process is conducted in stage 1. Furthermore, head section of the part is prepared for hexagonal shape in stage 2. The initial hexagonal shape is given to the part in stage 3. In stage 4, socket, flange and dog-point in the shaft is formed. At final stage reduction in the shaft is formed.

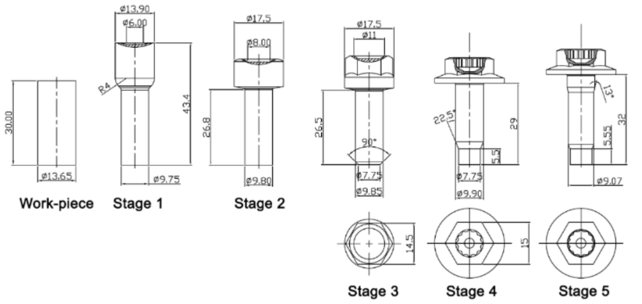


Figure 1. Forging stages of M10x32 dog-point bolt.

Technical drawing of stage 4 die couple is shown in Figure 2(a). Die system consists of moving and stationary die. Tool failure was seen on the die number 4 which forms dog-point section on the shaft. The picture of the failed tool is shown in Figure 2(b). As depicted in the figure, fracture started from the tool radius and propagated longitudinally though the outer diameter of the WC-Co insert. Surface cracking was also seen inside the tool cavity as depicted with the arrows in Figure 2(b). This type of failure seen on the forging tools is classified as forced ruptures and caused by excessive forging loads [16]. Because of that, forging load and tool stress distribution have to be investigated.

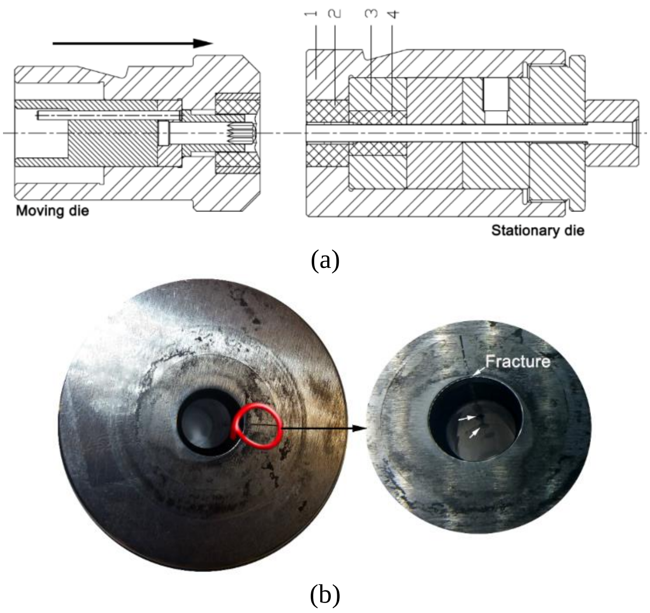


Figure 2. (a) Die system of stage 4; moving and stationary die, (b) the picture of fractured tool.

3. NUMERICAL MODELS

Numerical models of cold forging operation were prepared in Simufact.forming finite element software. Mechanical models were also coupled with thermal analysis to consider temperature effects on flow stress of the workpiece material. Examples of numerical models are shown in Figure 3. Stage 1 and 2 were simulated with 2D models due to the axisymmetry while 3D models were used for stage 3, 4 and 5. As shown in the figure, numerical models consist of stationary and moving dies and the workpiece. Dies were modeled as rigid. Due to high speed of the forging process, no heat transfer was defined between dies and workpiece. Workpiece material, DIN 1.5536, was modeled as plastic material and true stress-true plastic strain curves between temperatures of 20 an 400°C and strain rates between 1 and 50 s-1 was defined to the software. In 2D models, 5,000 quad elements were used in the mesh of the workpiece. In 3D models, half of the semi-formed part was modeled and symmetry plane was defined to decrease calculation time. Non-homogenous mesh distribution was used in 3D models. Smaller elements were used on the main deformation areas as depicted in Figure 3(b) and total 28,000 hex elements were used in the finite element mesh. Proper modeling of friction is crucial to get realistic material flow in metal forming simulations. In this study, temperature dependent Coloumb friction coefficient was defined to the software.

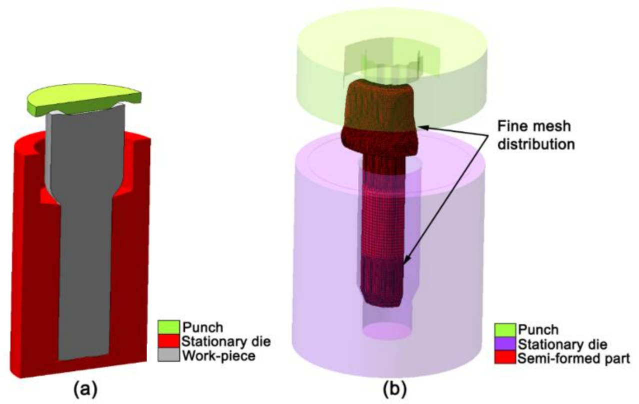


Figure 3. Examples of numerical models; (a) 2D axisymmetric and (b) 3D models.

After conducting forming simulations, tool stress analysis were carried out for stage 4. Numerical model of stationary die system is shown in Figure 4. Tool numbers in the figure are same with the ones depicted in Figure 2(a). Here, no.1 and no.3 are stress rings made of DIN 1.2344 while no.2 and no.4 are inserts made of WC-27%Co (G55). In the numerical model, stress rings and insets were assumed to be elastic materials. Elastic modulus and poisson's ratio of DIN 1.2344 and G55 are 215 GPa and 0.3 and 450 GPa and 0.22, respectively. The tensile strength of DIN 1.2344 is about 1380 MPa. Due to fracture evolution on no.4 insert, compressive (3000 MPa) and tensile strength (700 MPa) of G55 material were used failure criteria. Shrink fit was also considered in the tool stress analysis and 0.5% shrink fitting ratio was applied between stress rings and inserts. In the numerical model, dies no.3 and no.4 were fixed from the their lower surfaces in all directions and rotations. The forging force determined from forming simulations was applied to the elastic dies. Tetrahedral elements were used in the finite element meshes of inserts and stress rings. Each insert and stress ring consist of 154,000 and160,000 tetra elements, respectively. Fine mesh distributions were used on the fracture locus.

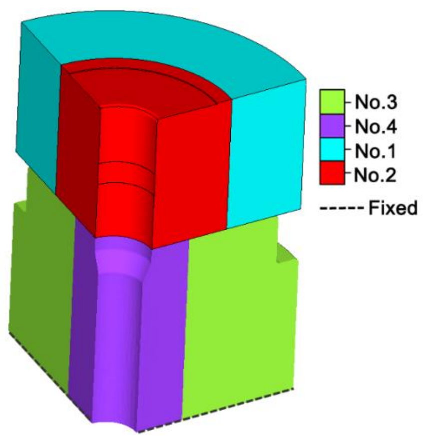


Figure 4. Numerical model of tool stress analysis in stage 4.

4. RESULTS AND DISCUSSIONS

Figure 5 shows the distribution of effective plastic strain on each forging stage. In extrusion process, stage 1, max. plastic strain value was found around 1.2 on the shaft. In stage 2, pre-heading operation was conducted and preparation form of socket was formed. Here, max. plastic strain reached 0.5 on the head while strain values on the shaft remained the same. In stage 3, hexagonal shape was given to the head section which increases plastic strain value to 2.2. Preparation for the dog point geometry was also formed on the end of the shaft and plastic strain reached 3.6 on this area. Final geometry of the head and socket were given in stage 4. Due to the excessive forming, plastic strain was found to be around 5. On the shaft, dog-point was formed and final plastic strain value was determined as 3.9.

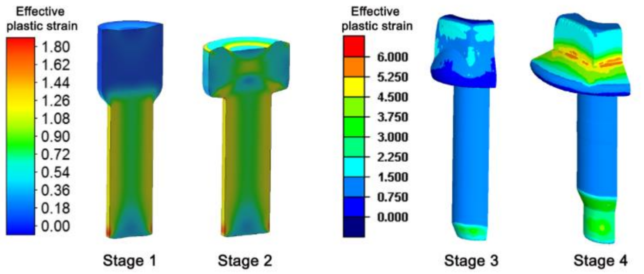
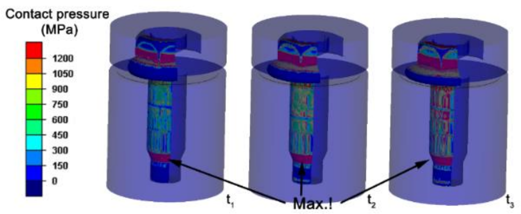
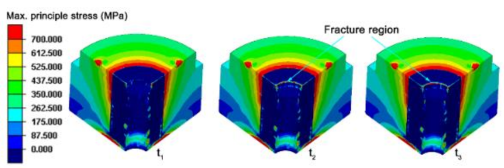


Figure 5. Distribution of effective plastic strain on forging stages.

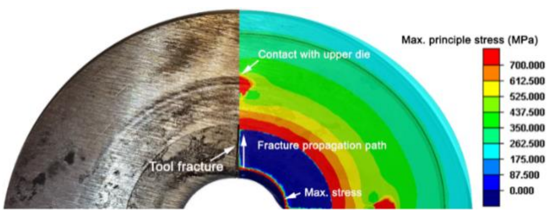
Contact pressure during forging of bolt head is a critical parameter to determine the critical locations on the tools during forging. For that reason, distribution of contact pressure was determined during forging as shown in Figure 6(a). After socket was completely formed, material was forced to flow through radial direction to form flange at t1 time . During the formation, punch pushes the part into tool cavity and this leads to generation of excessive contact pressure on the dog-point section. In other words, dog-point section carries high percentage of forging load alone. Naturally, this leads significant increase of tensile stress on the weakest point of the tool which is the end radius as depicted in Figure 6(b). Comparison of simulated and failed tool is shown in Figure 6(c). As seen from the figure, cracking starts from the radius and propagated through the outer diameter of the insert as a result of tensile stress. Prediction of the stress distribution was seen well matched with actual failure of the tool.



(a)



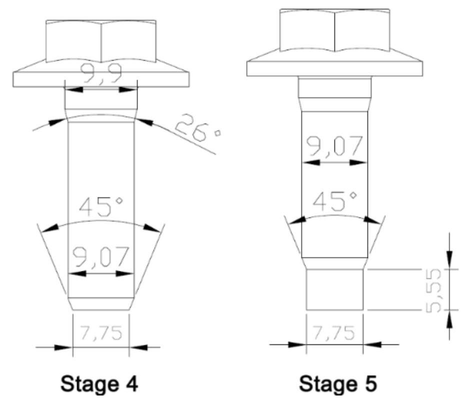
(b)



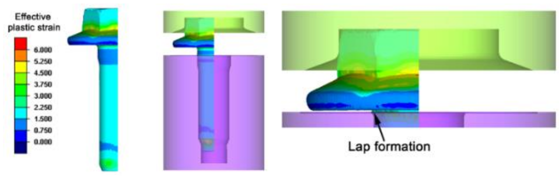
(c)

Figure 6. (a) Distribution of contact pressure at forging time of t1, t2 and t3 (t1<t2<t3), (b) max. principle stress distribution on dog-point tool (no.4) and (b) and (c) comparison of failed and simulated tool at t3.

As depicted in the above paragraph, contact pressure on the dog-point section during formation of flange and socket reached very high values, ~2500 MPa which leads crack initiation on the tool radius. To eliminate that, forging stage designs of stage 4 and 5 were changed as shown in Figure 7(a). Here, the reduction on the shaft having 26° on stage 5 was shifted to stage 4 and the dog-point formation was shifted from stage 4 to stage 5. Forming simulations were repeated with changed stage designs and lap formation was detected under the head of the part on stage 5 as shown in Figure 7(b). It was seen that material cannot flow easily through dog-point reduction area and this causes to expand of the shaft diameter under the head. Furthermore, expanded part of the shaft buckled with increasing pressure and leads to lapping. In order to ease material flow on dog-point section on the die, preparation and dog-point angle was decreased to 40° from 45°. Simulation showed that lap formation was avoided with that design chance as depicted in Figure 7(c).



(a)



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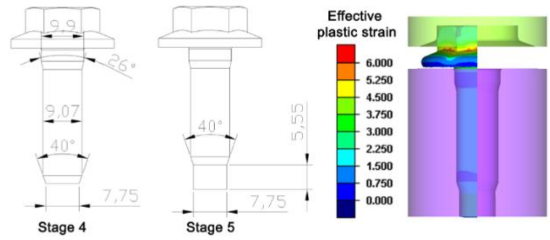

(c)

Figure 7. (a) Design chances on stage 4 and 5, (b) lap formation on stage 5, (c) final dimensions of stage 4 and 5 and formation of the part.

According to final design of stage 4 and stage 5 which are shown in Figure 7(c), tool stress analysis of stage 5 was carried out. At first, monolithic tool design was used as shown in Figure 8(a). In metal forging operations, tools are generally designed as monolithic. When tool failure occurs on some point, the tool is split from that point in which max. stress is generated. This tool design is called split design. Simulation showed that tool failed due to stress localization on the dog-point as depicted in Figure 8(b). Max. principle stress was found to be between 750 and 820 MPa on this location. In the further analysis, tool was split from the surface upper from dog-point section at 1.9 mm as shown in Figure 9(a). This method decreased the tool stress on dog-point to 175 between 250 MPa as depicted in Figure 9(b).

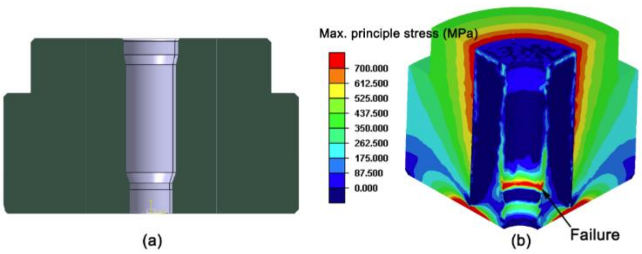

Figure 8. (a) Monolithic design of dog-point tool and (b) max. principle stress distribution.

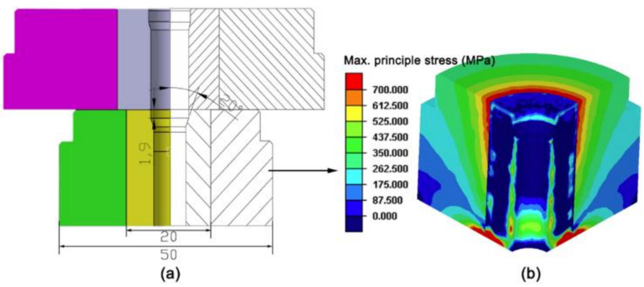

Figure 9. (a) Split insert design of dog-point tool and (b) max. principle stress distribution.

Bolt production with new tools were performed to investigate the effectiveness of the new design on tool life. Tool life before simulations was determined as 35,174 bolts per tool for forging of 1,000,000 bolts in production house. It was seen that 28 tools were failed during that production. This production costs extremely high due to tool cost, consumed energy and inactive time of the forging press during tool change. The life of new tools are shown in Figure 10 for forging of 1,500,000 bolts. Total of 11 tools were used and tool life was determined as 136,364 bolts/tool. This showed that tool life was increased about 3.8 times.

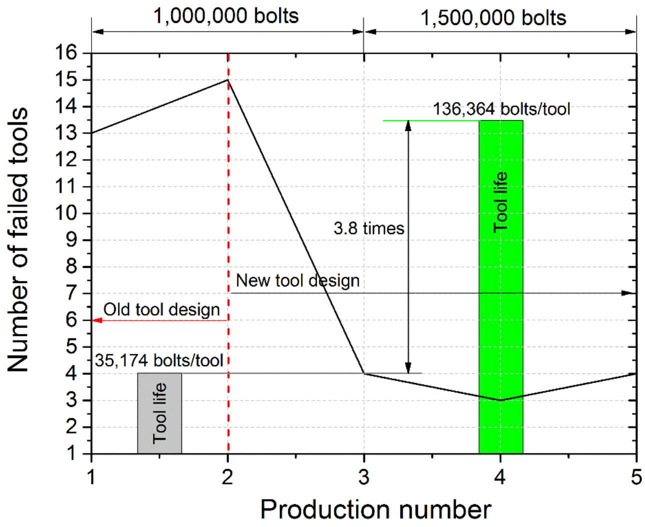

Figure 10. Comparison of tool life of old and new tools.

5. CONCLUSIONS

In the present study, multi-stage cold forging process of special M10x32 dog-point bolts was investigated numerically to analyze the reasons of tool failure and reveal the influences of forging stage design on tool life. Simulations showed that simultaneous forming of flange, socket of and dog-point section leads to generation of excessive contact pressure and tool fracture was triggered by high tensile stress. Flow of the material on dog-point section was found to be affected by reduction angle. While 45° dog-point angle slows the flow of material and causes expansion of shaft diameter and lap formation, forming problems were vanished with reduction of this angle to 40°. It was seen that tool stress can be reduced about 70% with proper modifications on forging stage designs which leads to increase of tool life 3.8 times in production..

REFERENCES

[1] T.-W. Ku and B.-S. Kang, "Tool design for inner race cold forging with skew-type cross ball grooves," *Journal of Materials Processing Technology*, vol. 214, no. 8, pp. 1482-1502, 8// 2014.

[2] K. Wagner, A. Putz, and U. Engel, "Improvement of tool life in cold forging by locally optimized surfaces," *Journal of Materials Processing Technology*, vol. 177, no. 1-3, pp. 206-209, 2006.

[3] B. He, "Failure and Protective Measures on Punch & Die for Cold Extrusion," presented

at the *The 2nd International Conference on Computer Application and System Modeling*, 2012.

[4] K. Andreas and M. Merklein, "Influence of Surface Integrity on the Tribological Performance of Cold Forging Tools," *Procedia CIRP*, vol. 13, pp. 61-66, 2014.

[5] S.-Y. Hsia and P.-Y. Shih, "Wear Improvement of Tools in the Cold Forging Process for Long Hex Flange Nuts," *Materials*, vol. 8, no. 10, pp. 6640-6657, 2015.

[6] P. Skov-Hansena, J. G. Niels Bayb, and P. Brùndstedd, "Fatigue in cold-forging dies: tool life analysis," *Journal of Materials Processing Technology*, vol. 95, pp. 40-48, 1999.

[7] S. Jhavar, C. P. Paul, and N. K. Jain, "Causes of failure and repairing options for dies and molds: A review," *Engineering Failure Analysis*, vol. 34, pp. 519-535, 12// 2013.

[8] H. J. Bunge, K. Pöhlandt, A. E. Tekkaya, and D. Banabic, Formability of Metallic Materials: Plastic Anisotropy, Formability Testing, Forming Limits. Berlin: Springer, 2000.

[9] M. Geiger, M. Hansel, and T. Rebhan, "Improving the fatigue resistance of cold forging tools by FE simulation and computer aided die shape optimization," Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*, vol. 206, pp. 143-150, 1992.

[10] H. Berns, A. Melander, D. Weichert, N. Asnafi, C. Broeckmann, and A. Groβ-Weege, "A new material for cold forging tools," *Computational Materials Science*, vol. 11, no. 3, pp. 166-180, 5// 1998.

[11] V. Vazquez, D. Hannan, and T. Altan, "Tool life in cold forging-an example of design improvement to increase service life," *Journal of Materials Processing Technology*, vol. 98, pp. 90-96, 2000.

[12] U. Engel and U. Popp, "Microtexturing of Cold-Forging Tools - Influence on Tool Life," Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*, vol. 220, no. 1, pp. 27-33, 2006.

[13] H. C. Lee, M. A. Saroosh, J. H. Song, and Y. T. Im, "The effect of shrink fitting ratios on tool life in bolt forming processes," *Journal of Materials Processing Technology*, vol. 209, no. 8, pp. 3766-3775, 2009.

[14] T.-W. Ku and B.-S. Kang, "Tool design and experimental verification for multi-stage cold forging process of the outer race," *International Journal of Precision Engineering and Manufacturing*, vol. 15, no. 9, pp. 1995-2004, 2014.

[15] S. Yurtdaş, U. İnce, C. Kılıçaslan, and H. Yıldız, "A Case Study for Improving Tool Life In Cold Forging: Carbon Fiber Composite Reinforced Dies," *Research on Engineering Structures & Materials*, 2016.

[16] K. Pöhlandt, "Testing tool materials for bulk metal forming," in Materials testing for the metal forming industry: Springer, 1989, p. 176.