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Stress Reduction and Lifespan Improvement in Cold Forging Marking Dies: A Comparative Study

[1] Afshin Zohdi, [2] Mesut Çiftçi, [3] Yunus Emre Uyanık

[1] Master of Science in Materials Engineering, R&D Engineer, Çetin Cıvata R&D Center
[2] Bachelor of Science in Materials Engineering, R&D Technical Office Supervisor, Çetin Cıvata R&D Center
[3] Bachelor of Science in Mechanical Engineering, R&D Center Manager, Çetin Cıvata R&D Center
Corresponding Author Email: [1] afshin.zohdi@cetin.com.tr, [2] mesut.ciftci@cetin.com.tr, [3] emre.uyanik@cetin.com.tr

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Abstract— ***This study investigates the performance and longevity of four different marking die designs (MD1, MD2, MD3, and MD4) used in the cold forging process for bolt production. The equivalent stress levels and life spans (production amounts) of the dies were analyzed using both simulation and experimental validation. The results indicate a significant variation in stress levels and life spans among the different designs. MD1 exhibited the highest maximum equivalent stress at 12068.5 MPa and the shortest life span with a production amount of 279,422 parts. In contrast, MD4 showed the lowest maximum equivalent stress at 4983.56 MPa and the longest life span with a production amount of 752,520 parts. These findings demonstrate that MD4's life span is approximately 2.69 times greater than that of MD1, while the stress level in MD1 is about 2.42 times higher than in MD4. The serrated design of MD2 and the non-intersecting serrated design of MD3 resulted in maximum equivalent stresses of 5885.89 MPa and 6308.73 MPa, with production amounts of 562,740 and 454,080 parts, respectively. These results confirm that incorporating serrations and reducing the number of sharp corners in the die design can significantly enhance the stress distribution and extend the die's operational life.***

Index Terms: Cold forging marking dies, die design, equivalent stress, finite element analysis.

I. LITERATURE REVIEW

Fasteners are indispensable components utilized across a myriad of industries, including automotive, aviation, and home appliance assembly. These small yet critical elements ensure the structural integrity and functionality of numerous products and machines. With the increasing demand for accelerated and more efficient production, fastener manufacturers are consistently seeking advancements in their production methodologies. Understanding the diverse methods of fastener production is thus imperative. The primary methods for producing fasteners encompass hot forging, cold forging, warm forging, and machining [1].

Hot forging is typically employed for the production of large fasteners that undergo significant diameter and volume changes during the forming process, performed above the material's recrystallization temperature [2]. Warm forging, conducted below the recrystallization temperature but above ambient temperature, offers a middle ground in terms of energy consumption and material properties [3]. Machining, performed at room temperature, provides precision but at a higher cost and material waste [4]. Cold forging, an economical and widely utilized process, also occurs at room temperature and benefits from the work hardening effect, enhancing the mechanical properties of the parts. Advantages of cold forging include minimal material waste, elimination of pre-heating requirements, rapid production flow, and the achievement of tight tolerances. However, the high forging loads required for this process induce significant stress on the forging dies, potentially leading to damage such as fatigue fracture, impact fracture, and wear [5], [6], [7].

Cold forging of fasteners involves the use of double-stroke or multi-stroke machines, which shape the fasteners across multiple stations. The number of stations is contingent upon the geometry and complexity of the fastener. At Çetin Cıvata, multi-stroke machines are employed, as illustrated in Figure 1.

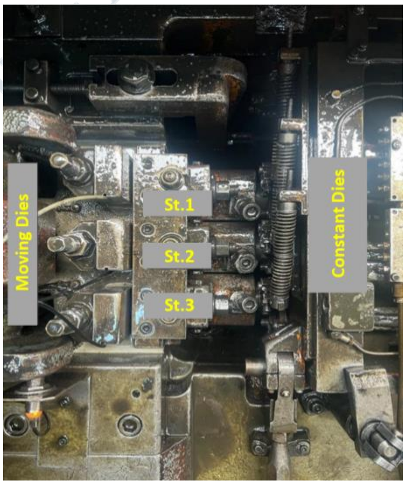


Figure 1. Cold forging die system, the marking die under investigation is located in the moving block at Station 2.

These machines operate with both moving and stationary dies at each station. The initial station forms the basic head shape, the second station, known as the marking die, further refines the head and applies the necessary markings, while the third station, termed the trimming die, finalizes the hexagonal head shape. Station two, in particular, faces challenges with premature failure during the production of DIN 933, M12*1.75*35 bolts, as depicted in Figure 2.

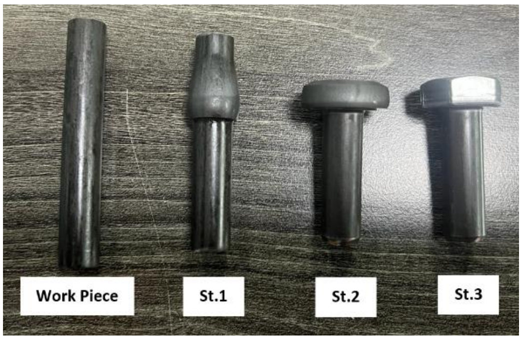


Figure 2. Station specimens of DIN 933 Hexagon Head Bolt, M12*1.75*35

Marking dies shape the workpiece by exerting horizontal impact, concurrently forming and marking the bolt head. The cyclic loading and unloading during the marking process contribute to fatigue damage [7]. The fatigue behavior of the marking die is influenced by variables such as surface quality, geometry, heat treatment processes, and hammer strength [8]. Additionally, friction arising from the workpiece spreading and shaping within the die cavity exacerbates fatigue wear. Abrasive wear may also result from die surface particle breakage, intensifying the wear condition.

The service life of cold forging dies is influenced by multiple factors, including operational press tonnage, die geometry, die material, surface finish quality, workpiece material strength, internal and surface stress intensities, wire rod surface quality, operator errors, inadequate lubrication/cooling, and friction coefficient [9], [10]. The tight tolerances between the die and product mean that even minor distortions can affect product geometry, resulting in quality issues and decreased production efficiency [11].

At Çetin Cıvata, marking dies are the most frequently consumed dies in bolt production, especially for bolts ranging from M3 to M27. Production line data indicate the highest consumption of marking dies occurs for M8 to M20 dies.

This project aims to extend the service life of in-house produced marking dies utilized on the production line. Existing literature suggests that die longevity is influenced by the manner in which markings are inscribed. Examination of similar bolts from various manufacturers revealed differences in marking geometry and the affected bolt head area. Initially, dies will be designed with different inscription types, and stress distribution on the die surfaces will be analyzed using SIMUFACT FORMING software. Subsequently, real dies will be fabricated and the simulation results will be validated through experimental tests to ascertain the optimal die design.

II. MATERIALS AND METHODS

A. Materials

The primary objective of this study is to enhance the lifespan of the marking dies utilized in cold forging. To achieve this aim, one of the frequently produced products at Çetin Cıvata, the DIN 933 Hexagon Head Bolt (M121.7535), was selected (Figure 1 illustrates the form of the workpiece at each cold forging station). The material being cold forged is 20MnB4. The chemical composition of 20MnB4 is detailed in Table 1.

Table I: Chemical composition of 20MnB4 (1.5525) steel used for production of the bolts

Chemical Composition (wt%)							
C	**S (Max)**	**P (Max)**	**Mn**	**Si (Max)**	**Cu (Max)**	**Cr (Max)**	**B**
0.18 - 0.23	0.025	0.025	0.9 - 1.2	0.3	0.25	0.3	0.0008 - 0.005

Additionally, the mechanical properties of 20MnB4 are presented in Table 2.

Table II: mechanical properties of 20MnB4 steel

Young's Modulus (GPa)	**Ultimate Tensile Strength (MPa)**	**Yield Strength (MPa)**	**Elongation (Min: %)**	**Hardness (HRC)**
190	580	400	25	39

For the marking dies, 1.2379 tool steel was chosen. Table 3 provides the chemical composition of this material.

Table III: Chemical composition of 1.2379 tool steel used for making marking dies

Chemical Composition (wt%)					
C	**Si**	**Cr**	**Mn**	**Mo**	**V**
1.55	0.40	12.00	0.40	0.70	1.00

The mechanical properties of 1.2379 tool steel are listed in Table 4.

Table IV: Mechanical properties of 1.2379 tool steel used for making marking dies

Young's Modulus (GPa)	**Ultimate Tensile Strength (MPa)**	**Yield Strength (MPa)**	**Elongation at Break (%)**	**Hardness (HB)**
190	760	470	16	230

B. Experimental Procedure and Simulation

To analyze the stress levels and distribution on the surface of the marking dies, four different types of dies were modeled using SolidWorks software. These models were then exported to SIMUFACT FORMING software to simulate the cold forging process at the second station, where bolt marking occurs. To validate the simulation results, dies identical to the modeled designs were fabricated. Figure 3 displays the images of both the modeled and produced dies.

The production of marking dies at our facility begins with raw material procurement. The supplied raw steel bar is cut on a CNC machine to achieve the desired dimensions. The primary cavity is machined in the machining department, and the inscriptions are engraved using a CNC pantograph in the tooling workshop. The marking die, machined to standard dimensions, undergoes heat treatment to achieve the desired hardness levels (54-60 HRC post-treatment). Finally, it is cold pressed into sleeves with a surface tolerance of 0.5%. Figure 4 shows a marking die placed in a sleeve.

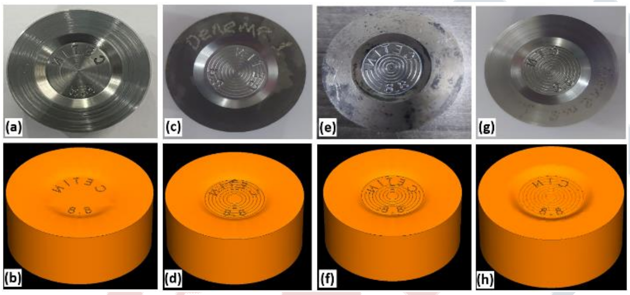
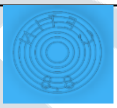


Figure 3. Produced dies and their 3D model Designed in Solidworks software

Figure 4. One of the marking dies that is placed inside the sleeve

As illustrated in Figures 3-a and 3-b, the first design features a flat surface with only inscriptions carved to a depth of 0.3 mm. The second type, shown in Figures 3-c and 3-d, includes concentric circles as well as letters and numbers, with the circles intersecting the letters and numbers, all carved to a depth of 0.3 mm. The third type, similar to the second type and shown in Figures 3-e and 3-f, has concentric circles that do not intersect the inscriptions. The fourth marking die, depicted in Figures 3-g and 3-h, is similar to the second type, but only the letters C, T, and N are carved instead of C, E, T, I, and N. To facilitate understanding, a coding system for the dies is introduced in Table 5.

Table V: Introduced coding system for marking dies

Die Name	**CETIN 8.8 Flat**	**CETIN 8.8 Serrated**	**CETIN 8.8 non-intersecting serrated**	**CTN 8.8 Serrated**
Die 2D Model Image				
Die Code	MD1	MD2	MD3	MD4

III. RESULTS AND DISCUSSION

A. Simulation Results

This section discusses the simulation results of the cold forging process for the marking dies. Figure 5 displays the modeled dies for each of the three stations in the cold forging process:

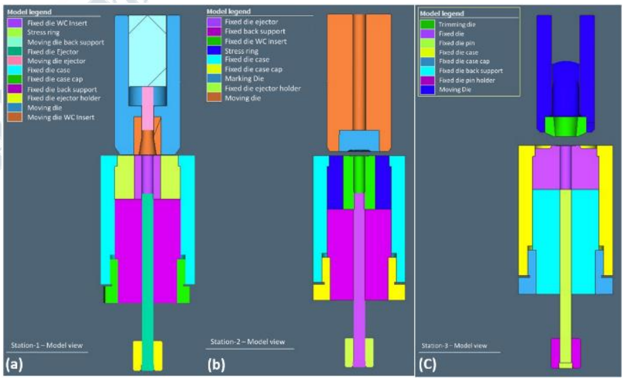


Figure 5. 3D model of each cold forging station die designed using SolidWorks software; a) station 1 (pre-forming die), b) station 2 (marking die), and c) station 3 (trimming die).

Figure 6 presents the simulation results for the MD1 marking die. It is evident that the maximum equivalent stress during the cold forging process reaches 12,068.5 MPa. This high stress level can reduce the lifespan of the marking dies and lead to premature failure.

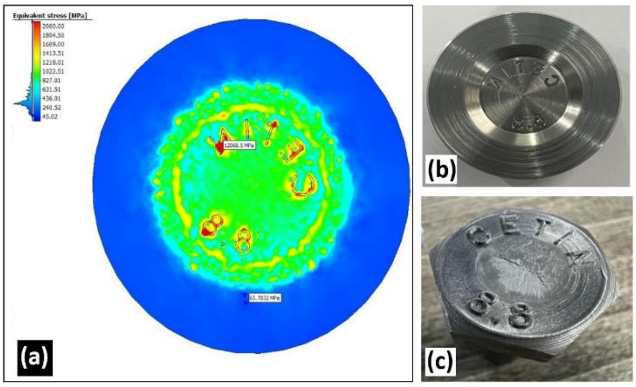


Figure 6. Results for MD1 die; a) equivalent stress distribution (MPa), b) produced marking die, and c) produced bolt with the marking die.

Figure 7 shows the simulation results for MD2. The maximum equivalent stress is 5,885.89 MPa, significantly lower than that for MD1. This reduction can be attributed to the serrations on the marking die surface, which promote a more homogeneous stress distribution and successfully reduce stress concentration at the sharp corners of the inscriptions.

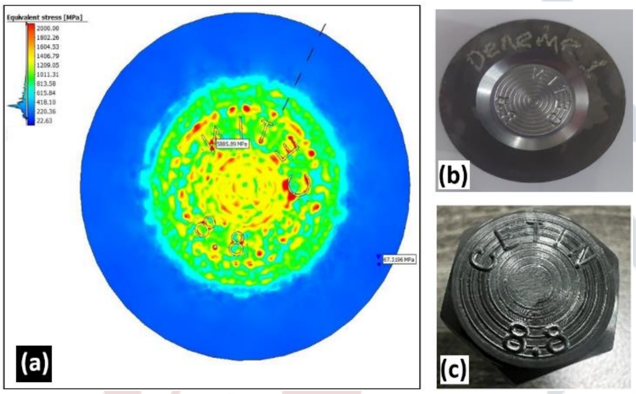


Figure 7. Results for MD2 die; a) equivalent stress distribution (MPa), b) produced marking die, and c) produced bolt with the marking die.

Figure 8 illustrates the equivalent stress for MD3. The maximum equivalent stress is 6,308.73 MPa, higher than that for MD2. The intersections between the inscriptions and serrations in MD2 effectively decrease stress concentration. The absence of these intersections in MD3 results in higher stress.

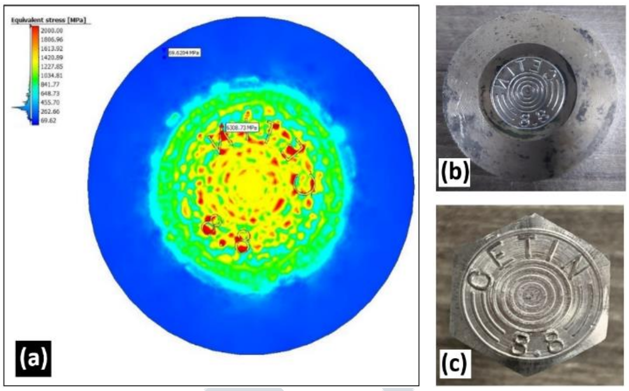


Figure 8. Results for MD3 die; a) equivalent stress distribution (MPa), b) produced marking die, and c) produced bolt with the marking die.

Figure 9 shows the equivalent stress for MD4, with a maximum stress of 4,983.56 MPa during the marking process.

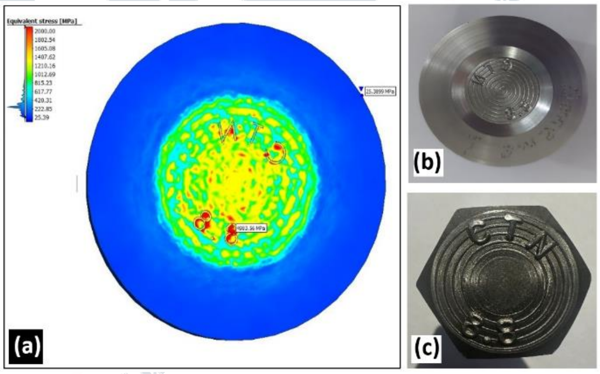


Figure 9. Results for MD4 die; a) equivalent stress distribution (MPa), b) produced marking die, and c) produced bolt with the marking die.

By comparing these results, it is apparent that MD4 and MD1 exhibit the minimum and maximum equivalent stress levels, respectively. A comparison between MD1 and MD2 highlights the effect of serrations on the marking die surface. The significant decrease in maximum equivalent stress observed in MD2 indicates that serrations contribute to a more uniform stress distribution on the die's contact surface.

Further, comparing MD2 and MD3 elucidates the effect of serration intersections with the inscriptions. The lower equivalent stress in MD2 suggests that intersections between serrations and letters reduce stress on the die's contact surface.

Lastly, the effect of inscriptions on equivalent stress levels can be discerned by comparing MD2 and MD4. The considerably lower stress in MD4, due to the reduced number of letters (E and I), implies that fewer sharp corners lead to less stress concentration, mitigating the risk of crack initiation and die failure.

The obtained results indicate that MD4 represents the optimal design among all tested dies.

B. Experimental Results

To validate the simulation results, four identical dies were produced and tested on the production line at Çetin Cıvata. Figure 10 summarizes the production amounts achieved with each marking die and the maximum equivalent stress from the simulations. The production data corroborate the simulation results, showing that the die with the highest maximum equivalent stress (MD1) had the shortest lifespan due to high cyclic stresses during production. Conversely, the die with the lowest maximum equivalent stress (MD4) exhibited the longest lifespan [12], [13].

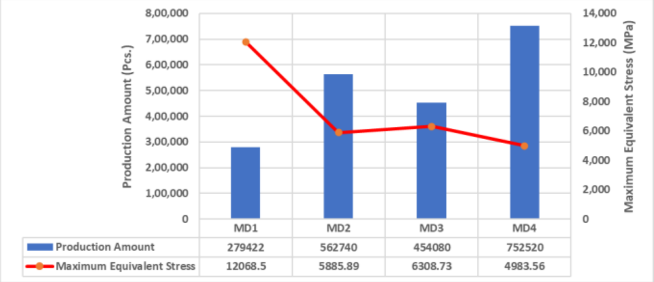


Figure 1. Production amounts and maximum equivalent stress for each marking die.

The experimental results confirm the simulation predictions, demonstrating that MD4, with the lowest equivalent stress, is the most durable design.

IV. CONCLUSION

The comparative analysis of the four marking die designs provides critical insights into optimizing die longevity and performance in the cold forging process. The study demonstrates that reducing stress concentrations through design modifications, such as serrations and fewer sharp corners, substantially enhances die durability. MD4, with the lowest equivalent stress and the longest life span, emerges as the optimal design, providing a production improvement of approximately 169% over the traditional flat-surfaced MD1. Additionally, the stress levels in MD4 are significantly lower, being approximately 142% less than those in MD1. These results underscore the importance of detailed design considerations in mitigating stress concentrations and improving the overall efficiency and cost-effectiveness of the production process. These findings offer a valuable reference for future design and manufacturing of marking dies, highlighting the potential for significant improvements in production efficiency and tool life through strategic design enhancements.

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