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**Original Article**

# The effects of failure types on cold forging dies

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**ABSTRACT**

Fastener preferences are also changing in parallel with the development of the automotive industry. During these periods, when light-weightings and carbon emissions have great importance; each part used is forced to be lighter, carbon footprints are calculated and more strength parts are designed. Therefore, the designs of manufacturing, sizes, and even raw materials of the fasteners used in the connections of the parts must be re-examined. This re-examination along with the manufacturers of fasteners supports scientific knowledge using advanced technologies, unique products, on behalf of the design of the production steps and the tool dies is of great importance. According to the complex geometry and strength quality of the bolt, product design and accordingly die designs are carried out. Due to its advantages in the manufacture of fasteners, the preferred method is cold forging. The production and design of cold forging die play an active role in terms of quality and production performance, as they directly affect the final product. Many factors affect the service life of molds in the manufacture of fasteners. In this article, the types of failures of cold forming molds, such as production stages, material selection, installation, relationship with the enterprise, are examined. The reasons for the failure of molds and manufacturing steps that are often encountered in production have been studied. In order to avoid these defects, recommendations have been made for re-mold designs.

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## INTRODUCTION

The application of fasteners in various industries is becoming an important factor due to weight reduction and carbon emissions especially in automotive [1, 2]. Therefore, the manufacturing of fasteners should examine to find solutions to these problems. Fasteners are produced in four processes, which are hot forging, cold forging, warm forging, and machining [2–5]. Hot forging is generally carried out for steel by forging in the austenite region for products with high diameters and high volume changes [1–3]. Warm forging performs below the re-crystallization temperatures and above the room temperature region [4]. Cold forging improves the strength of the metal by hardening it at room temperature. Also, fasteners could be produced by machining, which is performed at room temperatures [5, 6]. Moreover, studies are being carried out for efficiency with metal layer printers in the production of fasteners.

The manufacturing of bolts by cold forging does not need any external temperature. Due to the production rate, which is high in fasteners manufacturing by cold forging, is generally preferred [9]. The manufacturing of

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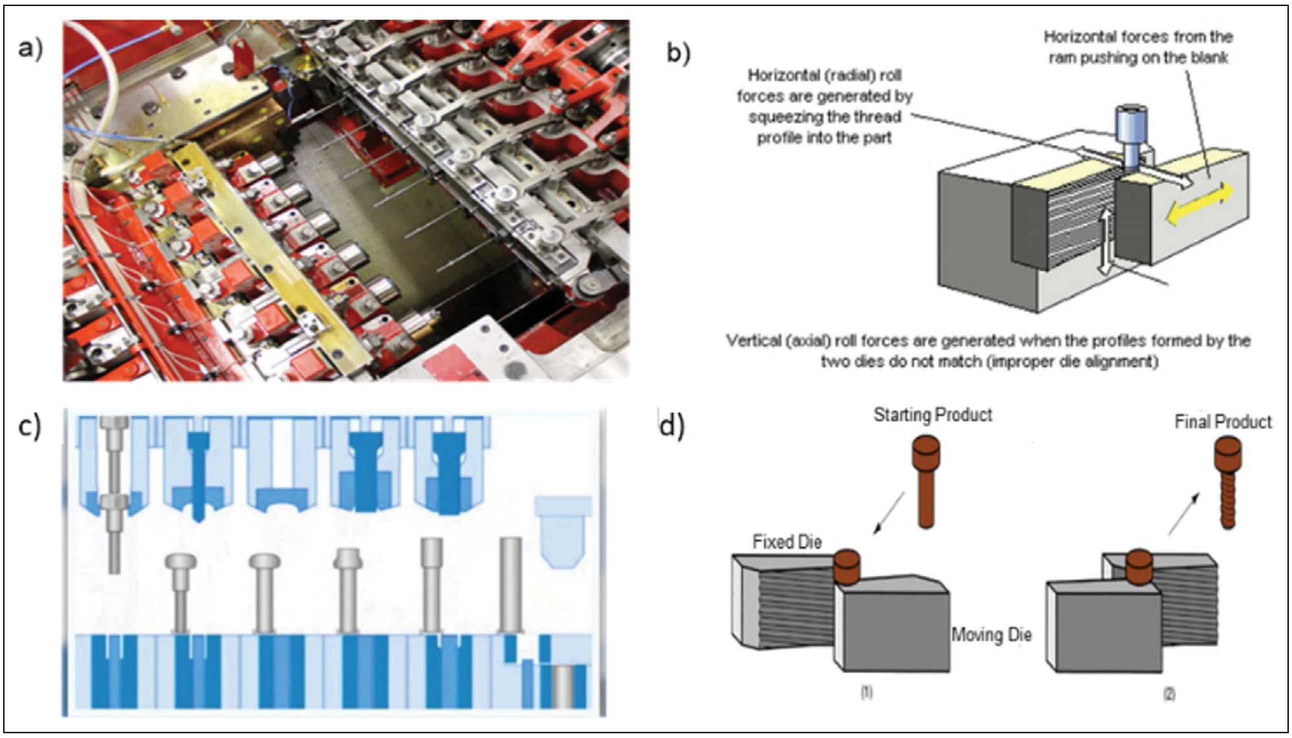


**Figure 1**. Illustrated **(a)** multi-stage cold forging bolt forming machine, **(b)** flat thread rolling, **(c)** illustration of cold forging operation within moving and fixed dies and **(d)** with flat thread rolling operation.

fasteners by cold forging starts by supplying the raw material rod or coil wire. First of all, surface cleaning and phosphate coating are applied to purify the wire surface oxidation, flaws and to reduce the surface roughness and friction coefficient by creating a lubricating medium between the dies [10–18]. The cold wire drawing process is applied to the supplied raw material. The drawn wires, the surface of which is cleaned, work on cold forging machines. As a thread process, suitable thread forms are given to the bolts by rolling movement between two threading dies without removing any chips by cold thread rolling methods shown in Figure 1. The threading process can be applied in three ways, namely rolling, forming, and machining. Thread rolling has advantages such as no scrap forming, fast production, and high strength by generating tension in the material flow lines compared to the other methods. Therefore, the thread rolling method is generally used in bolt production. The cold thread rolling process can be done in 3 different methods: flat, cylindrical, and planetary thread rolling, (also new methods are still investigated [19, 20]). After the cold forging processes, the desired strength quality is achieved by heat treatment process. To increase corrosion resistance, electro galvanization, hot dipped galvanization, acidic, alkali, Zn-Ni, Zn-Al, Cu, Zinc Lamellar, etc. coatings are applied to the final products [15, 16]. Finally, the packing and shipping fasteners set out to successfully fulfill their task of keeping the parts together.

The designs of the fasteners used are being developed taking into account the development of important sectors such as automotive, aircraft, and white goods and the effects of the carbon footprint on the world. Depending on this evolution, the design of cold forging dies follows the same path. Manufacturing steps start with product designs, which are made within the framework of the formability of the raw material, the raw material-tool relationship, the geometry of the product, manufacturability, and sustainability. Horizontal axis cold forging machines are used in bolt manufacturing. Production speeds reach levels that can produce 320 pieces per minute. The final product geometry of the bolt can be reached by two to six stages, depending on the bolt design, machine capacity, and depending on raw material deformation capability. The production steps of the bolt, which is used as an automotive special product, are shown in Figure 2. Cold forging machines have two groups: movable dies and fixed dies. Movable die parts apply pressure on the horizontal axis towards fixed dies. The fixed die traps the raw material part in it and takes the shape of the die and the geometry of the head in the designed step. The performance and duration of usage of the die used to have a very important place in terms of economy. Making suitable die design for each new product and operating the machine in the right conditions is very large expertise and an area that is open to development. There are quite a lot of studies in the literature on behalf of a cold forging die designs and lifetime increase studies [7, 8, 21–30].

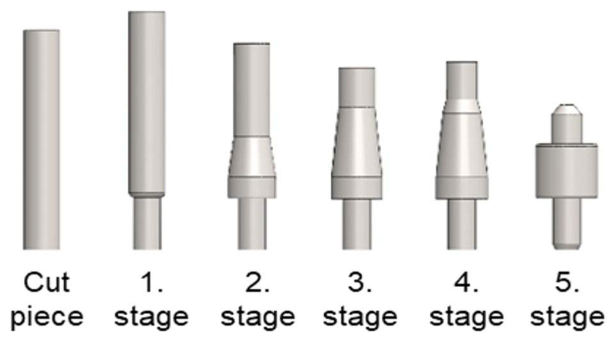


**Figure 2**. The manufacturing steps of the bolt cold forging operation steps.

### Manufacturing Steps of Cold Forging Dies Using Different Methods

The machining of the dies for the manufacture of cold-forged bolts usually follows these paths; die designs, supply of die tool materials, and trimming dies in suitable geometric dimensions. Rough machining with lathe or EDM, bringing the inner and outer diameters to the desired geometries with the surface, hole, and cylindrical grinding and polishing as a final process. After calculating and adjusting the shrink fit tolerances of the shell and insert materials, die parts are obtained by applying shrink fit. The process is completed with final machining and surface polishing.

The dies are mounted on the machine and the design axis is prepared by the operator. The working principle of the closed die method on the machines is that the movable die and the fixed die that press on the same horizontal axis are shaped inside by obtaining narrow geometric tolerance. After the forming process is finished, it is transferred to the next station with the transfer holders (Fig. 1a, c). For each station, the formability of the workpiece and the exposed loads of the station are calculated and designed. The slightest crack/deformation that may occur on the dies directly reflects the product. This causes a decrease in the quality of the product and directly affects the performance of the dies, increasing tool scraps [31, 32].

The shrink fit method is used in cold forging molds for the production of fasteners [22]. The shrink-fit rates are directly related to the life of the dies. [33, 34]. The shrink fitting technique is the assembly of two or more two materials together with a shrink fit. There are three types of shrink-fit processes which are sub-zero, hot, and cold. The main purpose here is to increase the performance of the die by reducing the effect on the material by dividing the radial and axial loads and stresses that affect the die during the operation. Material selection has a very important place in the shrink fit method [21, 35]. The proper insert and shell shrink fitting ratio and material should select by computing parameters such as geometric tolerances, microstructural, mechanical properties, and surface roughness of the materials that will shrink fit to

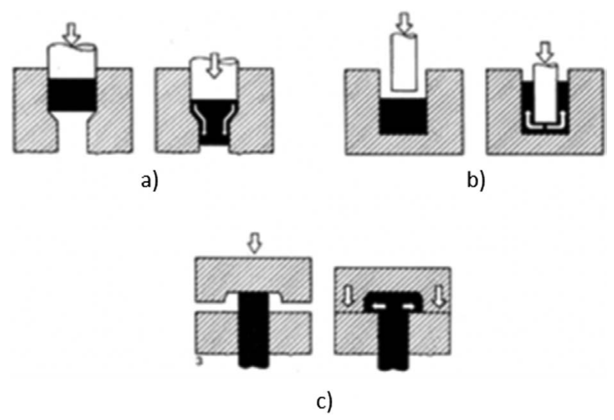


**Figure 3**. Cold forming types, **(a)** extrusion, **(b)** backward extrusion and **(c)** heading [31, 32].

each other. So that, resist the flexing of the hard insert, which is the die with which the raw material comes into direct contact, during operation, the outer shell should create a cushioning effect, reducing the stresses and loads on it, and provide mobility [31, 36, 39]. At the same time, it is extremely important for the geometry of the product that the insert materials cannot be deformed during the operation [7, 29, 37–39]. Mostly, Tungsten Carbide - Cobalt (WC-Co) materials are used as the insert to resist the high pressures and stresses of the raw material in the dies. While WC-Co material has high compressive strength and wear resistance, it is not resistant to tensile and shear loads.correct installation ratios should be determined, and processing and heat treatment should be applied accordingly. To be able to calculate or determine these values, finite elements analysis programs and material thermal properties can useful [42–44]. In this direction, geometric tolerances should be well defined. If correct and appropriate shrink fit, values are not given and machining operations are not carried out according to these tolerances, the life, and performance of the dies decrease. This is due to the extremely high stresses on the shell and the insert without tight fit [40]. If these stresses do not match the appropriate mechanical properties, they cause deformation and fractures [21, 45].

### Shrink Fitting Process of Insert and Stress Rings

Factors such as the roughness of the contact surfaces of the materials and the fracture toughness before the shrink fit, affect the homogeneous compression values. Cleaning of these surfaces should be done very carefully and accurately. At the same time, machining steps should take into account as they have a great impact on these tight fit values [45]. The shrink fitting values suitable for the designed diameters are processed according to the mechanical properties of the selected materials and the critical stress values to be released from the operations, and the shrink fit tolerances are determined and processed (Fig. 4a–c) [21, 46].

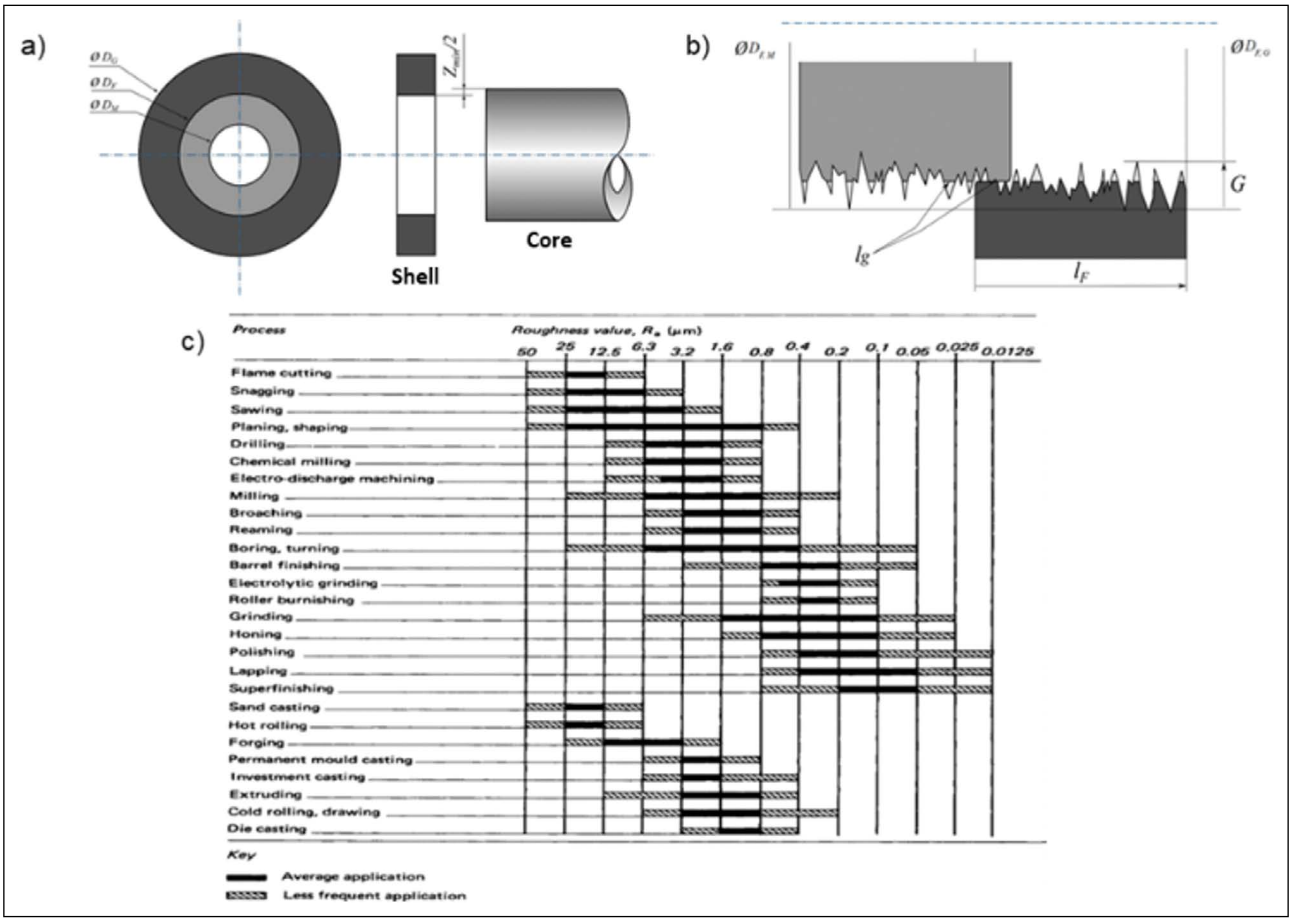


**Figure 4**. Shrink fittings **(a)** tight passage of the Shell and insert [35], **(b)** the relationship between the surfaces of materials that will assembly together, and **(c)** the average values of surface roughness of Ra left by manufacturing processes on materials.

**Relationship and Assembly of Dies between Cases**

Closed cylinder dies can consist of one or more parts [45]. cold forging dies are installed on machines. Cold forging dies are assembled on machines. Dies are designed according to the capacity and dimensions of the cold forging machines. Cold forging die parts are composed of many metal forming operations (Figure 3), such as reduction, extrusion, heading, marking, trimming, and segment. These parts must be installed inside the case coaxial with the hole diameters and parallel to the die surfaces (Figure 5).

There are many reasons for die failures in the bolt manufacturing processes. The most important ones are operator errors, material selection, lubrication, design, and incorrect die manufacturing steps or choices. In this study process of the effects of the manufacturing steps of cold forging dies, which is the main subject of this study, on the dies, a review was made by supporting the failure analyzes encountered in the manufacturing with the literature.

If the shrink fitting value is incorrect, failure types can occur. The main failure types of these breaks are based on, plastic deformation, wear, and fatigue failures mechanisms [45] Aygen, has done a wide range of studies on the breaking mechanics of molds and design-related improvements. The reasons for this failure of the cold forging tools studied in this study are consistent with the relevant studies and are shown in Figure 6 and Figure 7.

**Axial Cracks**

It would form starting from the inner surface or the shrink fit surface shown in Figure 6a and Figure 7b. Fractures originating from the shrink fit surface may be due to inhomogeneity of the shrink fit ratios or not being fitted correctly. The surface tensions that may be encountered in the manufacturing steps lead to these failures. Axial fractures starting from the inner surface, on the other hand, may occur because the material used as the insert cannot withstand shear or tensile stresses that may occur.

**Radial Cracks**

It happens because the insert is subjected to continuous cycle loads and stresses shown in Figure 6 and Figure 7a and 7c. These fractures could be classified as fatigue fractures. To prevent fatigue fractures, the inhomogeneity in the preload forces on the die should reduce to the minimum. This

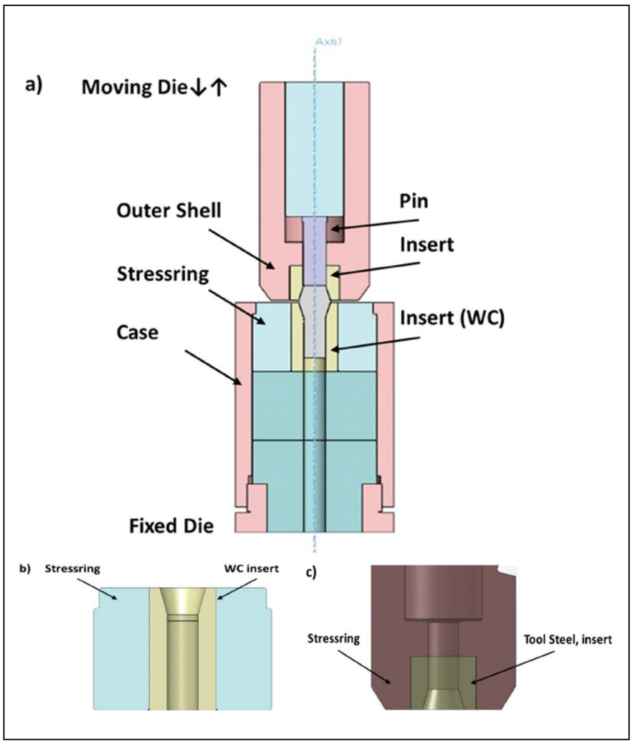


Figure 5. Parts of cold forging dies, (a) assembly drawing of moving and fixed dies, (b) reduction and (c) heading die.

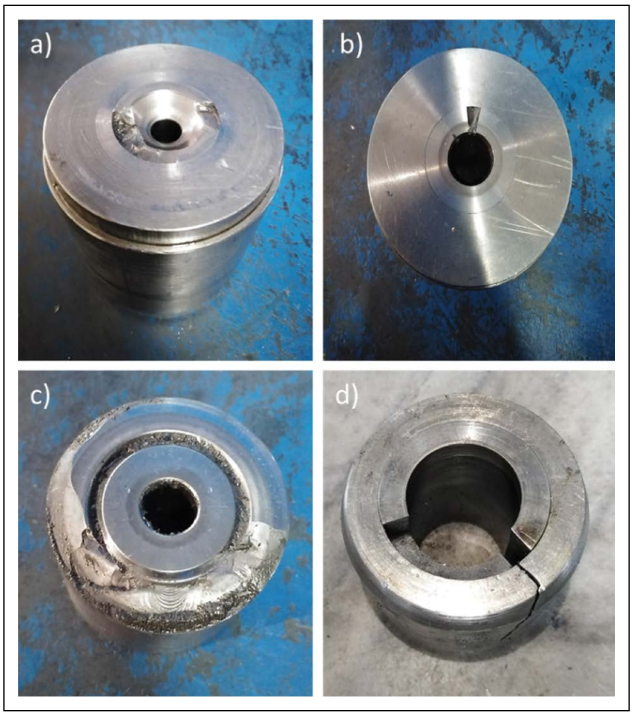


Figure 7. Failures in dies (a) radial crack of insert, (b) axial crack of insert, (c) outer radial crack of insert and (d) axial crack of both stress-ring and insert.

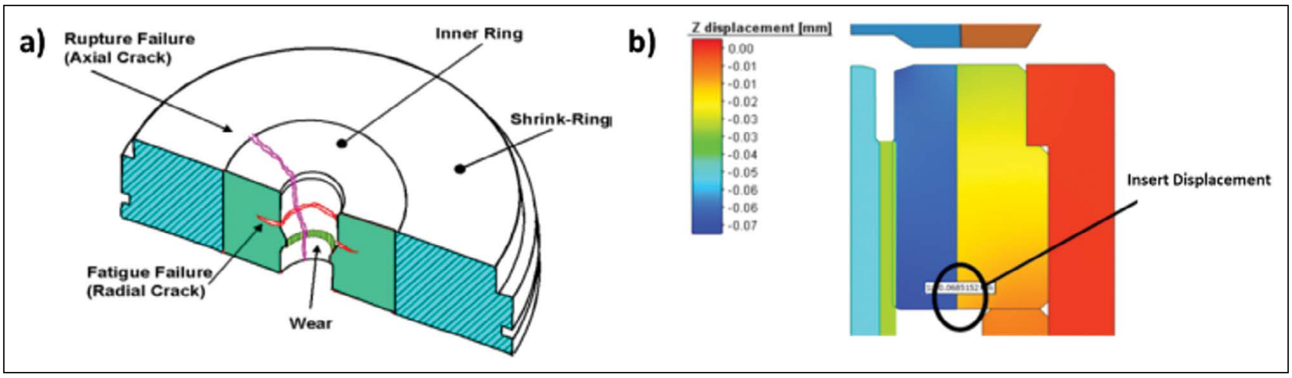


Figure 6. (a) die failures in cold forging and (b) insert sliding simulating with Simufact (NETFORM).

definition of inhomogeneity can also be processed as the relationship between surface roughness and tool material, starting from the tool quality, microstructure effects of the tool it contains. These inhomogeneities are among the factors affecting fatigue life and crack initiation. The surface roughness along the area where the insert and stress-ring contact, is one of the main factors affecting the fatigue life and fatigue fractures.

### Insert Movement Defects

It is due to the inability to provide the appropriate shrink-fit according to the forcing conditions. If the shrink fit ratios are higher than the optimum values, the surface tensions that affect the shrink fit surfaces can be quite high. Therefore, with the external stresses released during the operation, these loads can cause stresses above the yield limit of the stress-ring material, so that the die can't show the shrink fit values by deforming. Formation of the insert displacement failure type can be realized by giving excessively high or low shrink fit rates. Given the high shrink fit ratio, high tensile amounts can be achieved from the contact surface of the materials. When radial and tension stresses are added during loading, the stressing plastic can be deformed and slide through the insert. An analysis of this situation is made in Figure 6b. To find the required shrink-fit values, we need to calculate or simulate the conditions. There are many studies on this subject in the literature. These studies are mostly design-based FE simulation studies [21, 37].

**Stress-ring Failures**

The production steps and used manufacturing methods of shrink fit materials are very important in terms of die integrity and performance. The cold forging process and the shrink fitting create high stresses on the shell. Due to the microstructural irregularity of the shell, it can easily cause fractures in the shell. Excessively high or low shrinkage rates and unusual breaks or core play in stresses that occur during loading can be caused by the fact that the tensioning material was not selected correctly or the quality of heat treatment.

## CONCLUSION

When the reasons for the breakage of cold forging molds are examined and analyzed, manufacturing steps and production methods are quite important. Along with the analysis of errors in production and the literature studies, the causes and determinations of the types of errors that are often encountered in cold forming molds are given. In the manufacturing of cold forming dies, shrink-fit ratios, die installation, cracks types, stress ring conditions, material selection, and application should be designed and manufactured.

In addition, die life has a very important place in terms of product performance and cost. Any deformation experienced in the molds is directly reflected in the quality of the fasteners produced.

**Data Availability Statement**

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

**Author's Contributions**

Talha Çakmak: Contributed to the design and comparison of the research, to the analysis of the results, and to the writing of the manuscript.

Şevki Alp Adaçağlar: Contributed to the design and comparison of the research, to the analysis of the results, and to the writing of the manuscript.

**Conflict of Interest**

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Ethics**

There are no ethical issues with the publication of this manuscript.

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