INVESTIGATION OF THE EFFECT OF PRE-DEFORMATION SHAPE ON COLD FORMING PROPERTIES IN THE PRODUCT MATERIAL IN FASTENER PRODUCTION

by

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Due to product features such as production quality and high surface quality, cold forging and cold extrusion methods are widely used in the production of fasteners. Extrudability plays a key role during the process and is affected by many process parameters. Die shape characteristics directly affect cold deformation. In particular, deformation hardening is influenced by the shape characteristics. The cold extrusion process also significantly affects mechanical properties. In this study, the effect of die shape characteristics on the extrudability of 20MnB4 (EN 10263-4) low carbon steel was investigated. Additionally, finite element analysis was conducted to optimize extrudability. Radiuses, angular, and radius-angular die shapes were used in the experimental and finite element analysis. The SIMUFACT FORMING software was used for finite element analysis. Both experimental and finite element analysis results showed that die shape significantly affects the extrudability of steels. Extrudability of steels can be optimized with the die shape. The highest homogeneous metal flow was obtained in the sample obtained from the radius-angular die shape. Samples with an angular die shape showed the lowest extrudability feature. Hardness and finite element analysis results were consistent.

Key words: *extrusion, cold forming, finite element analysis, stress and strain*

Introduction

Nowadays, fasteners can be seen in almost every field. Their ability to hold multiple components together makes them preferred in all industrial areas that require assembly processes. Fasteners ability to be repeatedly disassembled and reassembled, along with their standardized nature making them easily available, results in their widespread use across all sectors of the industry. In recent years, the use of fasteners in high-safety-demanding industrial areas such as the automotive industry has increased competition in this field, making the design and production processes of these components even more critical [1-3]. The design of fasteners produced worldwide by cold forming consists of multiple forming operations. Stamping and extrusion methods are commonly used in these operation steps. In fasteners, the process of forming the material by inflating under compressive forces is called stamping, while the process of narrowing the cross-section of the material is called extrusion. The cold extrusion method, used to reduce the workpiece to the desired size in the design of fasteners, is widely applied in the production of many parts with simple and complex shapes [4, 5].

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While applying the cold extrusion method, undesirable deformations may occur in the internal and external structure of the workpiece depending on the extrusion parameters. The ability to predict these deformations at the design stage of the part can only be achieved with the knowledge and experience gained after many years [6]. Therefore, by supporting the design with the finite element method, the manufacturability of the part and the errors that may occur in the part can be predicted. With the widespread use of the SE method in the production of fasteners by cold forming in recent years, the accuracy of the design can be known before production. In addition, the mold lifetimes used can also be calculated [7]. In this way, the use of the finite element method increases the quality of the product and provides labor, cost and time savings during production [8-10].

Literature studies are usually done either experimentally or numerically. Optimization studies conducted by combining experimental and numerical studies are limited. Onder and Aygen [11] compared experimental and numerical calculations in the problems encountered in the production of fasteners in their study. Then, they compared their optimization studies experimentally and numerically, and as a result, they achieved successful results and emphasized the importance of the finite element method. Likewise, Baygut *et al.* [12] compared experimental and numerical studies in cold forging and fastener production in their study and saw that the data obtained gave similar results in their diagrams.

The effect on availability was investigated. In addition, all experiments carried out to optimize the process parameters were analyzed with the finite element method. The SIMUFACT Forming software was used as the finite element software.

Experimental studies

The 20MnB4 low carbon steel according to EN 10263-4 standard was used as test material [13]. The chemical composition of the steel used is given in tab. 1.

Table 1. Percent chemical composition of EN 10263-4 20MnB4 material (% by weight)

C	Si	Mn	$P_{\max}$	$S_{\max}$	Cr	$\mathrm{Cu}_{\max}$	B
0.18-0.23	<0.30	0.9-1.2	0.025	0.025	<0.30	0.25	0.0008-0.005

In order to produce test samples, cold forging dies to be extruded with a cross-section shrinkage of 54% were designed and the test set was created using multi-stroke bed press machines to perform the test at room temperature. The crank diameter of the press machine is 210 mm, the connecting rod length is 495 mm, and its speed is 55 rpm.

The AUTOCAD and CAD programs known as CATIA were used in the design of extrusion dies. In mold making, three different mold geometries were used. The primary mold material is G50 and G40 types of tungsten carbide material. The other mold material is 1.2344 hot work tool steel, also known as X40CrMoV5-1. Three different sample-die geometries were used in the production of extrusion dies. Solid models and technical drawings of radius, angled, and radius-angle dies used respectively are shown in fig. 1. The die, die sets and die cut used in experimental studies are given in fig. 2.

In the production of the test samples, multi-stroke forging presses traditionally used in the production of fasteners were used. The operation steps of the set produced in multi-stroke horizontal presses are given in fig. 3, and the sample pictures obtained at each station.

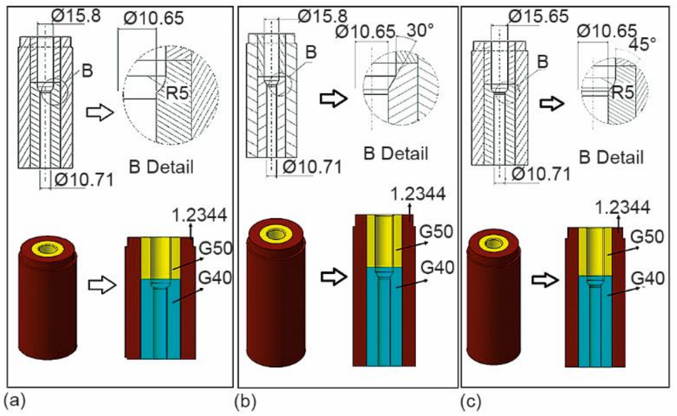

Figure 1. Drawings and solid models of dies; (a) radius extrusion die, (b) angle extrusion die, and (c) radius-angle extrusion die
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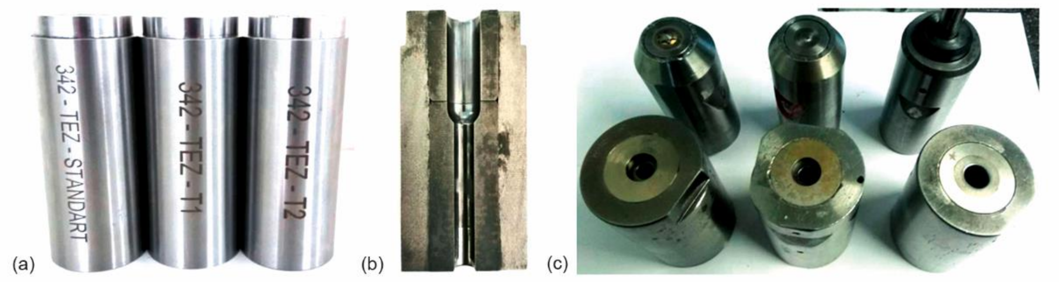


Figure 2. Produced extrusion dies and test die set; (a) extrusion dies with different forms, (b) cross-section of the produced extrusion die, and (c) experiment die set used in sample production

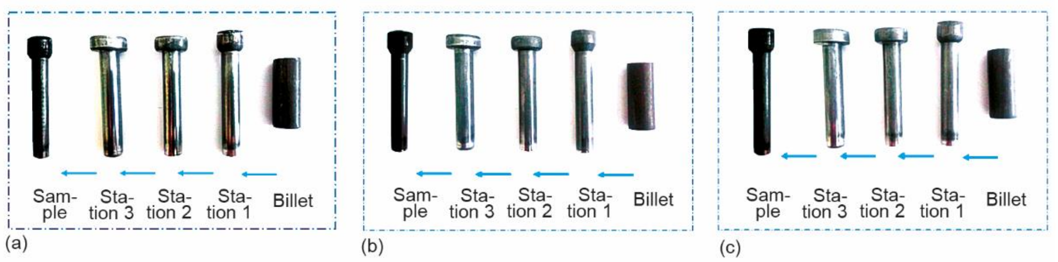
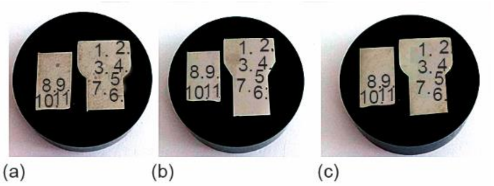


Figure 3. Processing steps of samples produced according to different extrusion die-sample forms; (a) radius extrusion die, (b) angled extrusion die, and (c) radius and angled extrusion die

In order to determine the effect of mold-sample form properties, metallographic examinations of all test samples at each station were made. In order to carry out metallographic examination, the samples were etched with HCl (boiling with hydrochloric acid). Images were obtained with a Nikon brand stereo microscope. Tensile tests were carried out in a Zwick/Roell Z250 test device with a tensile and compression capacity of 250 KN. Three samples were tested). In order to carry out the hardness tests more clearly, hardness tests were carried out on all test samples at each station. After standard surface sanding, polishing and etching processes,



(a) (b) (c)

Figure 4. Hardness measurement points on bakelite of the samples produced according to different extrusion dies; (a) radius extrusion die used, (b) angle extrusion die used, and (c) radius and angled extrusion die used

hardness measurements in HV1 were made from the sample surfaces with the emcoTEST DuraScan brand hardness device. Bakelite samples are given in fig. 4. The hardness measurement sequence is given in fig. 4.

The SIMUFACT FORMING finite element software was used to optimize the experimental results. Numerical analyzes were carried out using a total of 2067 quads type mesh elements in the mold and 1170 in the sample in the mold and sample models. In the finite element program, the parameters of the experimental set were written exactly as stated in the experimental set, and numerical analyzes were carried out. Since cold extrusion was performed in the experiments, data at room temperature were used in the analysis. In the finite element software, the effect of sample forms on the stress distribution was investigated. Loads from the same molds were evaluated.

Experimental results and discussion

Effect of die form properties on extrusion flow properties

In order to determine the effect of mold form properties on extrusion flow properties, the flow forms of the produced samples were examined by macro etching, figs. 5 and 6. When fig. 6 is examined, it is seen that the continuity of the extrusion flow line is best obtained in the radius-angle sample. This continuity can be explained by the fact that the rad-angle sample is subjected to a more uniform force during extrusion than other samples. These continuities occurring in the flow line also cause tension concentrations in this region.

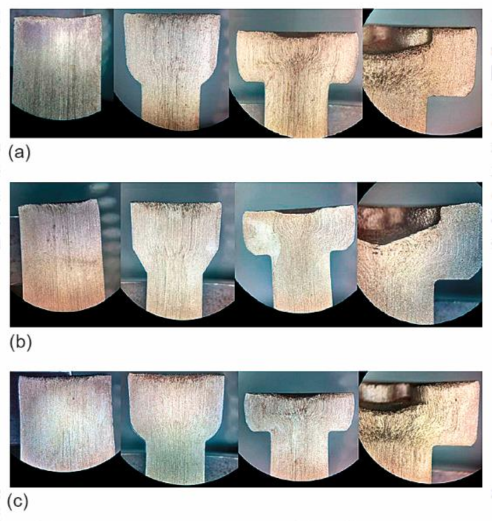

(a)
(b)
(c)

Figure 5. Macro images of samples produced according to different extrusion dies; (a) radius extrusion die is used, (b) angle extrusion die is used, and (c) radius and angled extrusion die is used

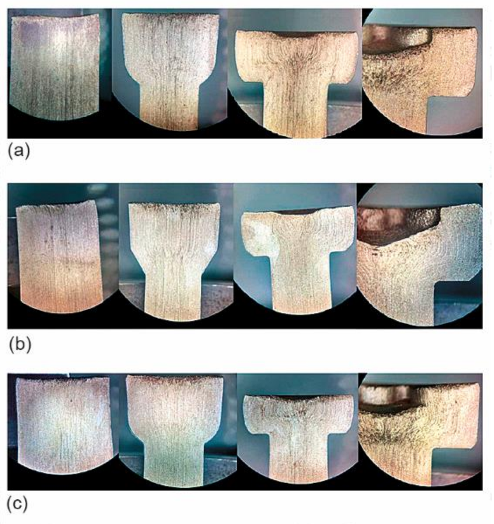

(a)
(b)
(c)

Figure 6. Macro images of extrusion samples produced according to different extrusion molds

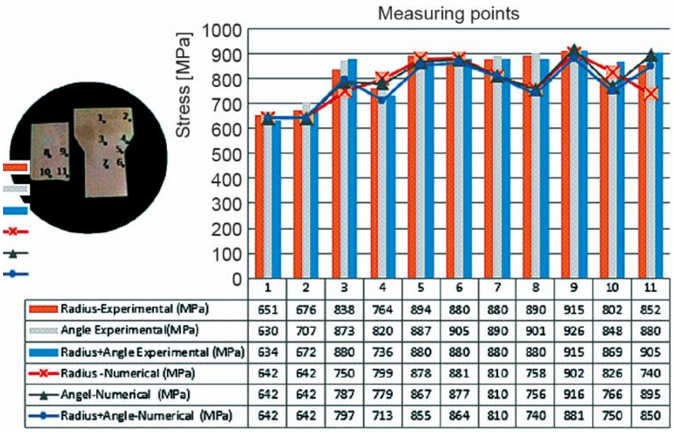
Set results

In order to determine the effect of mold form properties on the extruded product properties, hardness measurements were made from eleven different regions (points) on the extruded sample. The HV1 hardness results obtained from the hardness measurements were converted to yield strengths [MPa] by using the formula obtained by E. Tekkaya's experimental studies [14].

	1	2	3	4	5	6	7	8	9	10	11
🟥 Radius-Experimental	651	676	838	764	894	880	880	890	915	802	852
🟩 Angle-Experimental	630	707	873	820	887	905	890	901	926	848	880
🟩 Radius+Angle-Experimental	634	672	880	736	880	880	880	880	915	869	905

Figure 7. Experimental and numerical analysis of the data obtained according to the hardness measurement zones in the radius-angle mold sample (*for color image see journal web site*)

As can be clearly seen from figs. 7 and 8, the mold form directly affects the hardness, in other words, the hardening rate. Considering the beginning and end points of the section narrowing, it is seen that the lowest yield strength values are obtained in the radius-angle sample. On the other hand, high yield strength values were mostly obtained in angled mold samples. At a remarkable point, it was determined that the radius and radius-angle samples showed similar yield strength values at many points. This effect on yield strength can be explained by the fact that the radius form in the mold guides the sample better during extrusion and facilitates sample flow. The highest yield strength values were obtained in the 9th region of all samples. These high values are attributed to being the point at which the section narrowing that occurs during extrusion first begins.



	1	2	3	4	5	6	7	8	9	10	11
Radius-Experimental (MPa)	651	676	838	764	894	880	880	890	915	802	852
Angle Experimental(MPa)	630	707	873	820	887	905	890	901	926	848	880
Radius+Angle Experimental (MPa)	634	672	880	736	880	880	880	880	915	869	905
Radius -Numerical (MPa)	642	642	750	799	878	881	810	758	902	826	740
Angel-Numerical (MPa)	642	642	787	779	867	877	810	756	916	766	895
Radius+Angle-Numerical (MPa)	642	642	797	713	855	864	810	740	881	750	850

Figure 8. Experimental and numerical examination of the data obtained according to the hardness measurement zones in the radius-angle mold sample (*for color image see journal web site*)

Tensile test results

Table and graphic results of the tensile test performed with three different samples are given in tab. 2. When the results obtained are examined, it is clearly seen that the hardening effect and the increase in yield strength of the samples applied with cold forming and forging are also observed.

Table 2. Tensile test test results

No.	$R_{p0.2}$ [Nmm^{-2}]	R_m [Nmm^{-2}]	F_m [kN]	S_0 [mm^2]
1	801	831	70.09	84.30
2	802	835	70.42	84.30
3	802	834	70.33	84.30

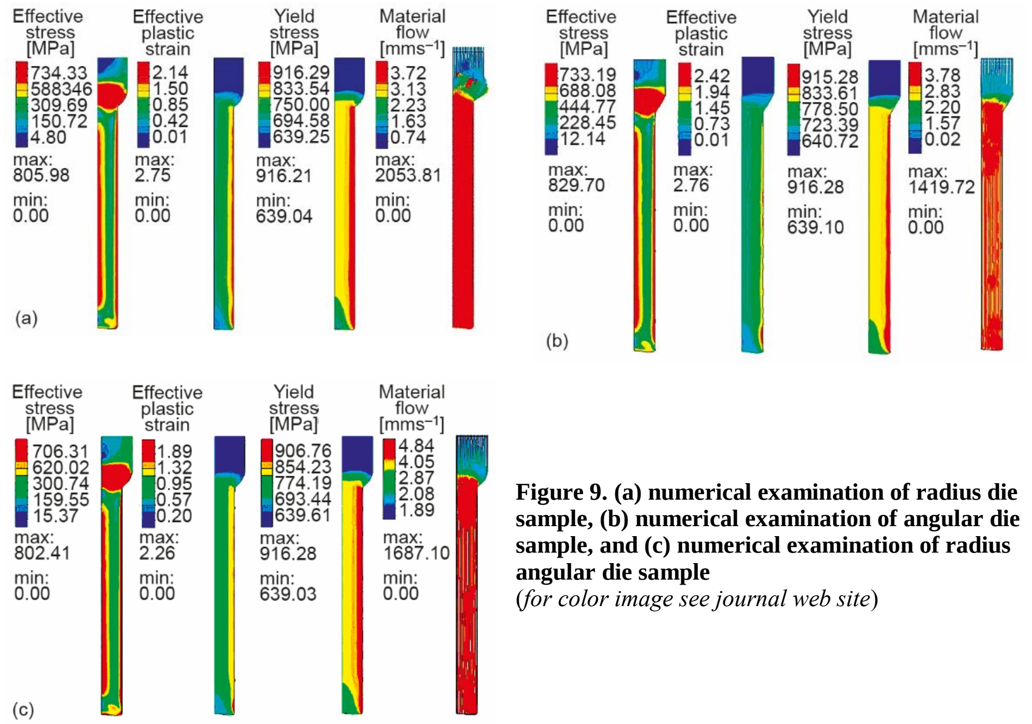


Figure 9. (a) numerical examination of radius die sample, (b) numerical examination of angular die sample, and (c) numerical examination of radius angular die sample
(*for color image see journal web site*)

In order to determine the effect of die form properties on extrudability, the results obtained in modeling studies with finite elements were examined in detail in terms of equivalent stress, equivalent strain, yield strength and material flow, fig. 9. When fig. 9 is examined, the mold form properties effectively change the stress-strain and material flow properties. Especially in plastic deformation theories, it is of great importance to separate the elastic and plastic regions from each other. For this reason, the evaluation of equivalent voltage results is of great importance. When the equivalent stresses of the radius, angle and radius-angle samples were examined, it was determined that close values were obtained. This result shows that the equivalent stresses in the sample are similar even though the geometry forms are changed. This result can be explained by the fact that the material properties do not change during the analysis. On the other hand, when the material flow images are examined, it is seen that the highest homogeneous flow is in the radius-angled sample. This result shows that the radius-angle form facilitates the material flow and reduces the hardening rate. Extrusion at high volume ratios can also be achieved with the radius-angle sample.

In order to determine the effect of die form geometry on extrudability in detail, the forces acting on the determined area on the die were evaluated by numerical analysis method. In fig. 10, the effects of the forces generated on the mold during the extrusion shaping of three different sample forms are given according to the 42 pieces of data taken during the shaping process. It can be clearly seen from fig. 9 that the geometry of the sample form directly affects the forces on the mold. The lowest force was obtained in the radius-angle sample, while the highest force was obtained in the angled die form. The radius mold form can be evaluated as the average of the other two molds. The variation in forces can be explained by the effect of die geometry on metal flow during extrusion. Since the stress generated during metal flow in the radius-angle sample is minimal, the force on the die is at the lowest level. When fig. 10 is examined in detail, another remarkable point is that the mold form features have an effect on the stability of the forces formed on the mold during extrusion. When fig. 10 is examined in general, it is clearly seen that the forces acting on the mold can be directly optimized by controlling the mold geometry. Die geometry directly affects metal flow, hardening density, extrudability. Extrudability can be optimized only by mold form properties without changing the mold material.

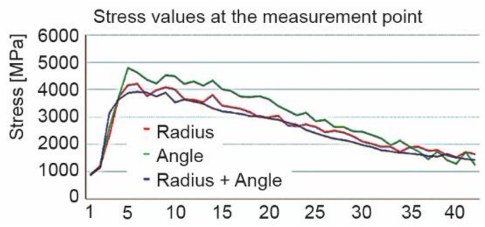


Figure 10. Graph of stress distributions in the extrusion zone of the dies
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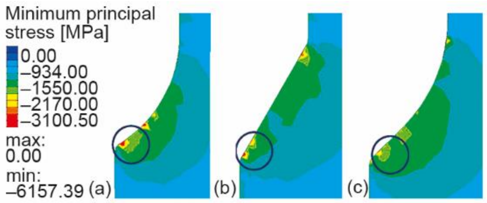

Figure 11. Stress distribution according to mold geometries; (a) radius, (b) angle, and (c) fillet-angle
(*for color image see journal web site*)

The voltage distributions of the measured regions are given in fig. 11. It can be clearly seen from fig. 11 that the stress distribution in the measurement areas on the die is directly affected by the die form, although the extrusion rate remains the same. As can be seen in fig. 11, it is seen that stress concentrations are the least in the radius-angled die form, while stress concentrations occur especially at sharp corners in the angled die form. This result can be explained by the formation of a more homogeneous strain hardening during extrusion. As a result of the inhomogeneity of the metal flow during extrusion, regional deformation hardening (hardening) occurs and this causes the formation of regional stresses. In the form of a radius die, it is seen that false stresses occur at the starting point of the radius. This type of stress is caused by the mismatched transitions of geometries, which are frequently encountered in numerical analysis software. This result is in parallel with the literature studies.

Conclusions

Molds with different form characteristics (radius, angled, and radius-angle) were produced and extrusion process was carried out in these molds. In addition to the experimental studies, finite element analyzes of molds with different forms were also carried out. The results and suggestions obtained from the experimental study and finite element analyzes are given as follows.

- Die form properties directly affect the extrudability of low carbon steels.
- Extrudability of low carbon steels can be optimized with die properties.
- The radius and angled form on the mold directly affect the metal flow.
- The highest extrudability was observed in radius-angle shaped molds.
- The highest stress distribution was obtained in angled shaped molds and samples
- It has been determined that it can be extruded by the finite element method and can be optimized in terms of equivalent stress, equivalent strain and yield strength criteria.
- In the cold extrusion process, the forces acting on the mold can be optimized by using the finite element method.

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