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Original Article

Investigation of Cutting and Ironing Performance of DC04 EN10130 Experimentally and Numerically

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Abstract

Fine blanking is a method used for the manufacture of sheet metal parts with narrow dimensional tolerances and where the cutting surface quality is desired to be much superior compared to conventional cutting methods. Sheet material properties and the design of the cutting die, ironing clearance and machining parameters are important factors in fine blanking of metals. In this study, the fine blanking and ironing process for the crank felt made of DC04 EN10130 cold rolled steel quality sheet metal with high impact resistance and strength, which is used in the production of automotive spare parts, was investigated by the finite element method. In the study, the simulation results with a cutting gap of 1, 3, 6 percent and a spinning ratio of 0.5, 7.5%, among the die geometries designed for the target geometry, and the experimental results were in good agreement with each other.

Keywords: Sheet Metal Forming, Burr Forming, Clearance, Geometric Tolerance, Ironing

DC04 EN10130 Kesme ve Ütüleme Performansının Deneysel ve Sayısal Olarak İncelenmesi

Özet

Hassas kesme işlemi, dar boyutsal toleranslara sahip ve kesme yüzey kalitesinin, geleneksel kesme yöntemleri ile karşılaştırıldığında çok daha üstün olmasının istendiği sac parçaların imalatı için başvurulan bir yöntemdir. Sac malzeme özellikleri ile kesme kalıbının tasarımı, kesme boşlukları ve işleme parametreleri metallerin hassas kesebilmesinde önemli bir faktördür. Bu çalışmada otomotiv yedek parça üretiminde kullanılan, yüksek darbe dayanımına ve mukavemetine sahip DC04 EN10130 kalitesindeki sac mamulden krank keçesi için hassas kesme ve sıvama prosesi sonlu elemanlar metodu ile incelenmiştir. Yapılan çalışmada hedef geometri için tasarlanmış kalıp geometrilerinden kesme boşluğu %1, 3, 6 ve sıvama oranını da %0, 5, 7.5 olan simülasyon sonuçları ile deneysel sonuçlar birbirleri ile büyük oranda uyum göstermiştir.

Anahtar Kelimeler: Sac Metal Şekillendirme, Çapak Oluşumu, Boşluk, Geometrik Tolerans, Ütüleme

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1. INTRODUCTION

Cutting operation in sheet metal forming is widely used in the automotive, aerospace and white goods sectors. Can be performed using hydraulic or eccentric (mechanical) presses for sheet metal materials. Depending on the characteristics of the dies used press, high precision and smooth products can be obtained. Burrs are formed on the surfaces of the products produced with the traditional cutting method. On the cutting surfaces, the rolling zone cutting zone and tearing zones are formed and the characteristics of these areas affect the product quality. In a cutting operation, sheet metal is fixed between the cutting die and the blank holder, and sheet metal is cut with the help of a stapler. Considering a traditional sheet metal cutting method, the stapler pushes the sheet into the die clearance and plastic deformation occurs until the beginning of a crack on the cutting surface. Part is deformed by plastic, by appling force from stapler and the cutting operation is completed with the progression of this crack [1, 2].

Clearance between dies, friction, thickness of materials and staple/die sizes are the main parameters affecting burr formation in trimming/cutting processes [3, 4]. After the cutting die is contacted with the material, the forces affect the size of the sheet metal material burr.

Since the part is separated from the main body by cutting in the first stage of the cutting process, the cutting surface is bright and the surface roughness values are low. In the continuation of the cutting process, the matte is observed in the surface and rough in the ruptured part, since the workpiece is separated from the main material. On the cutting surface, the first crack gives direction. Sheet metal materials produced by traditional cutting method usually have cracks on their surfaces. For this reason, the quality of the cut surface affects the product and the cut surface cannot exceed a certain level [5, 7, 10]. The geometric dimensions in the manufactured part cannot enter narrow tolerance ranges. Therefore, burrs are taken from cut surfaces and it can cause additional costs.

Fine blanking method is a sheet shaping method using high-tech presses and die that allows materials to be cut along their thickness without the need for a second main operation, without allowing any tearing and rupture. Due to these advantages, fine blanking is more preferred in sheet metal processing operations today than other methods [6]. The precision in the geometric dimensions of the products to be produced with fine blanking and the minimum amount of burrs in the cut corners show the advantage of fine blanking.

In the fine blanking method, the sheet is compressed with a high-pressure force between the cutting die (perimeter cutter) and the printing die. The part to be cut is pushed into the die clearance by the stapler and the cutting process is carried out. In fine blanking, the clearance must be less than 1% of the material thickness. Due to the characteristics of fine blanking, it is possible to cut 100% of the material thickness completely and obtain flat and non-plus free surfaces. In the classical cutting method, it is cut with only 30% material thickness. In other parts, rupture occurs [6].

In the fine blanking process, die elements must be of sensitive sizes and rigid structures. The part of sheet metal whose surfaces are compressed under high pressure, forced into plastic flow along a very narrow cutting clearance, exhibits an extrusion-like behavior by being exposed to a high hydrostatic pressure. In this way, the main sheet can be cut along the desired line. Due to plastic deformation caused by slip strain, the cutting surface is bright; surface roughness values are very low. Burrs are often not observe in sheet metal parts manufactured by fine blanking process. In this way, production time and operational costs are greatly reduced.

The size of the cutting clearance depends on the type and thickness of the cut material. As the cutting clearance shrinks, the cut surface becomes smoother. However, when the very small cutting range is left, the power required for cutting is excessive due to increased friction and accumulation. This can cause early blunting of cutting edges or cutting circles, or even breakages in the cutting edges. In the case of large cutting clearance, it causes burrs and high stresses in the sheet metal material to be cut [8]. The clearance of die is the radial distance between the die and punch, the edge is usually characterized by four divisions as shown in Figure 1.

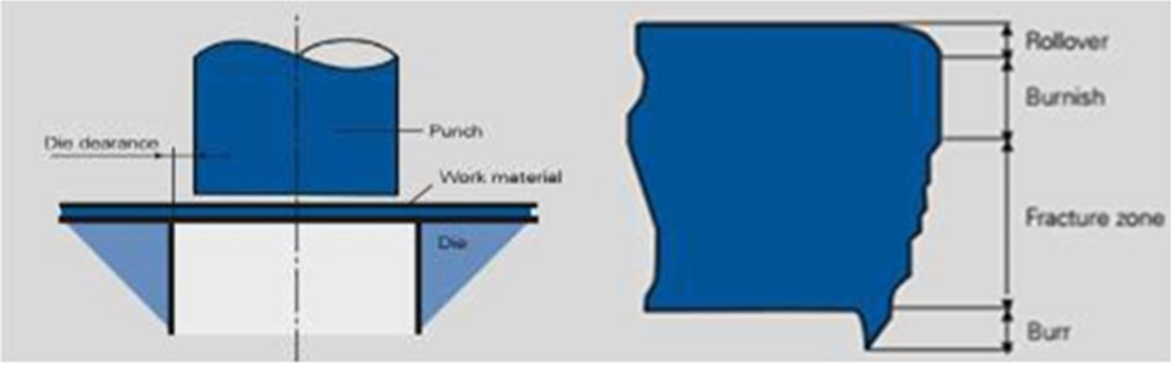

Figure 1. Die Clearance Definition and Appearance of a Cut Edge [9]

Within the scope of this study, the cutting clearance, which is the most important of the fine blanking process parameters of DC04 EN10130 sheet metal widely used in the manufacturing industry, was examined experimentally and numerically. The dimensional tolerances formed in the corner parts of the part were examined.

2. MATERIALS AND METHODS

DC04 EN10130 sheet metal material, which is in high demand in the manufacturing sector, is a cold rolling product and is frequently used in the white goods sector in the automotive sector. Chemical components of DC04 EN10130 material shaped in designed dies for the study are given in table 1. It has significant advantages in the forming tribality of the material, which is the basic alloying element C.

Table 1. Chemical Composition of DC07 EN10130 Cold Rolled Steel

C (wt%)	0.063
Si (wt%)	0.009
Mn (wt%)	0.249
P (wt%)	0.011
S (wt%)	0.009
Cr (wt%)	0.037
Ni (wt%)	0.03
Cu (wt%)	0.073
V (wt%)	0.001

Figure 2 displays the flow curve obtained at a tensile speed of 25 mm/s of sheet metal with a thickness of 0.8 mm and other mechanical properties of the material are given in table 2.

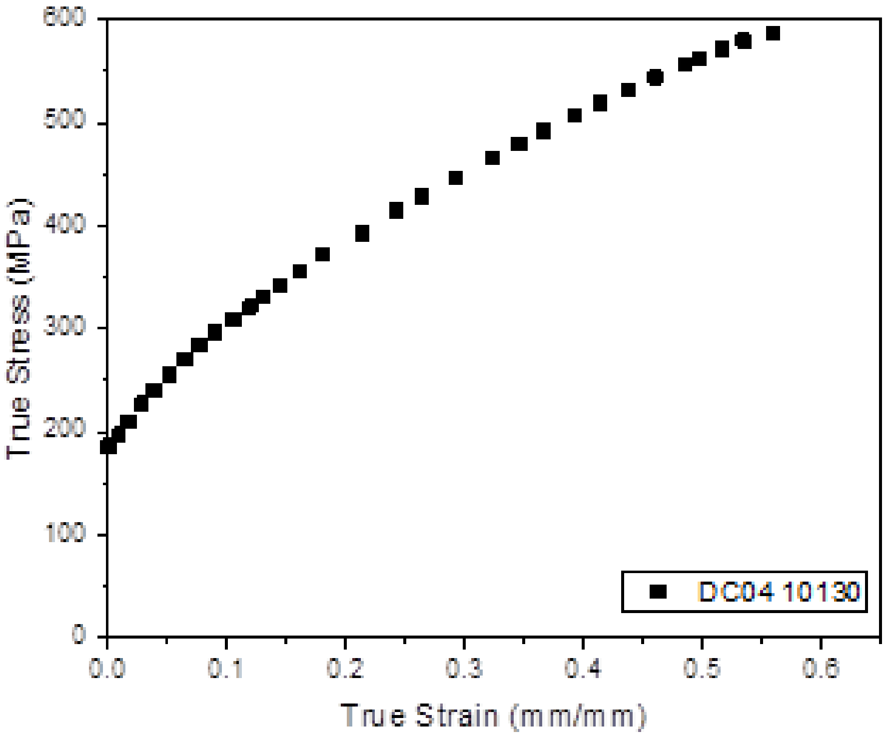

Figure 2. Flow Curve of DC04 EN 10130

Table 2. Mechanical Properties of DC04 EN 10130 Cold Rolled Steel

Material	DC04 EN10130
E (MPa)	185000
$\sigma_{0.2}$ (MPa)	186
σ_{UTS} (MPa)	332.7
K (MPa)	657
n	0.31
R_0	1.85
R_{45}	1.25
R_{90}	2.25

Within the scope of the study, a die system containing different cutting clearance and ironing rates for 0.8 mm DC04 EN 10130 sheet material is shown in figure 4. According to the parameters determined here, deviation rates are determined numerically according to the geometric tolerances of the workpiece after the forming process. In forming simulations, the cut clearances are selected as 1, 3, 6% and the ironing rates are selected as 0, 5, 7.5%.

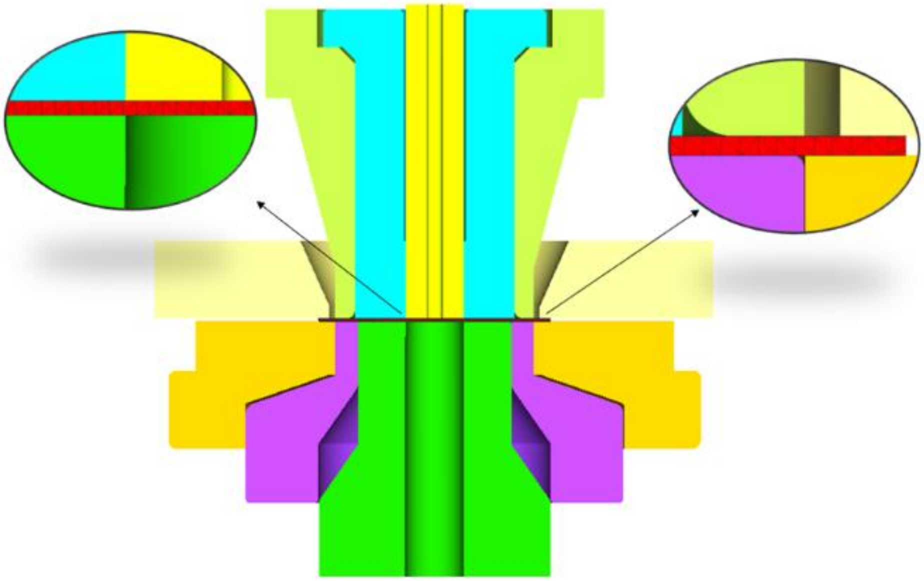

Figure 3. Cutting and Ironing Die System View

Simulations of cutting and ironing operations were carried out using the Sheet Metal Forming module of commercially available Simufact (MSC Software) program. Die elements in the system are considered rigid. Surface interactions between die elements and sheet metal material are modeled according to the Coulomb Law. According to this law, the friction coefficient 0.1 was used in the analysis. In the finite element's analysis model, the temperatures of the media, sheet/workpiece and die parts are taken at 20 °C. Adiabatic warm-ups caused by plastic deformation and temperature increases caused by friction and its effects on the mechanical behavior of sheet metal material were ignored. Damage model used in the FE analysis was carried out using the normalized Cockroft-Latham perch material refractive mechanics model and the relevant model is given in equation 1 [11].

$$\int_0^{\varepsilon_f} \frac{\sigma_{max}}{\sigma_{eff}} . \varepsilon_{eff}^{pl} \mathrm{dt} \geq \mathrm{C} \tag{1}$$

In simulations, one of the important tool that is used to calculate the stress state of the materials is the yield function. In the study, quadratic Hill 48 anisotropic yield function is used, and the related formulation in the three-dimensional stress state is given in equation 2.

$$2f(\sigma_{ij}) \equiv F(\sigma_y - \sigma_z)^2 + G(\sigma_z - \sigma_x)^2 + H(\sigma_x - \sigma_y)^2 + 2L\tau_{yz}^2 + 2M\tau_{zx}^2 + 2N\tau_{xy}^2 = 1 \tag{2}$$

Here f is the flow function, and F, G, H, L, M, N are the anisotropic parameters which can be calculated via Lankford parameters. In the case where the prime axes of the tensor coincide with the anisotropic axes ($\varepsilon_x = \varepsilon_1$, $\varepsilon_y = \varepsilon_2$, $\tau_{xy}=0$), the Hill-48 flow criterion is given in equation 2, which is given due to principal stresses.

In the simulations, as hardening curve, Hockett-Sherby mathematical model is defined due to the performance on the prediction of the stresses. The related parameters of the model and fitted curve is depicted in Fig. 4. Hockett sherby equation equation 3 is shown. The data to be used in the analyzes are given in Table 3.

$$\sigma_f = b - (b - a).e^{-m.\varphi^n} \tag{3}$$

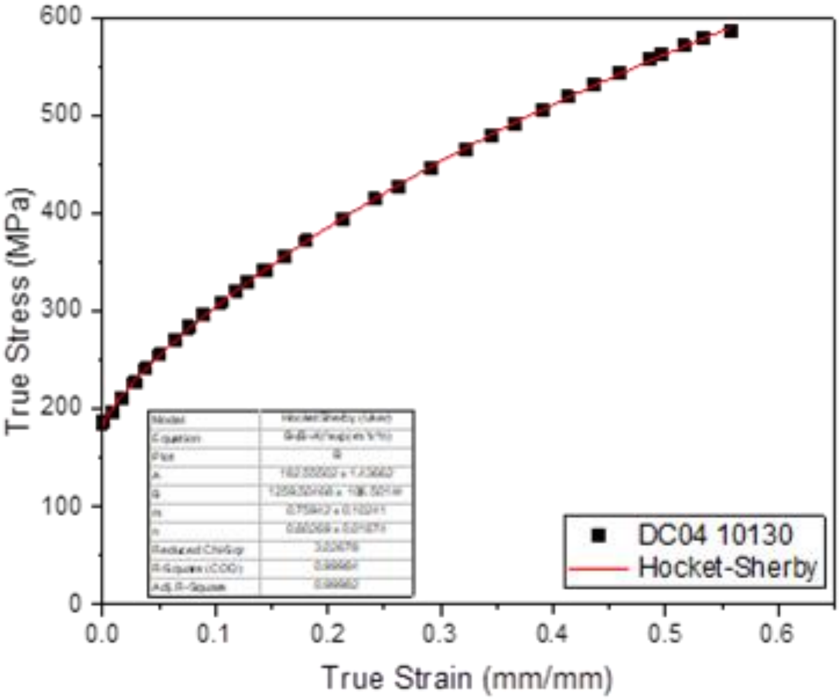

Figure 4. Hockett-Sherby Flow Curve Model

Table 3. Hockett-Sherby Constants

a (MPa)	186
b (MPa)	1358.89
m	0.92761
n	0.78547
φ	2

Figure 5 shows the mesh structure of the workpiece to be produced in the cutting and ironing die system. The mesh type of the workpiece quadtree was determined and the element type quads (10) was used. In this way, the workpiece had 16082 elements. Refinement boxes mesh has been added to the surfaces where the cutting will be made. Thus, mesh structure was provided more dense in that area due to the visualize the burr formation.

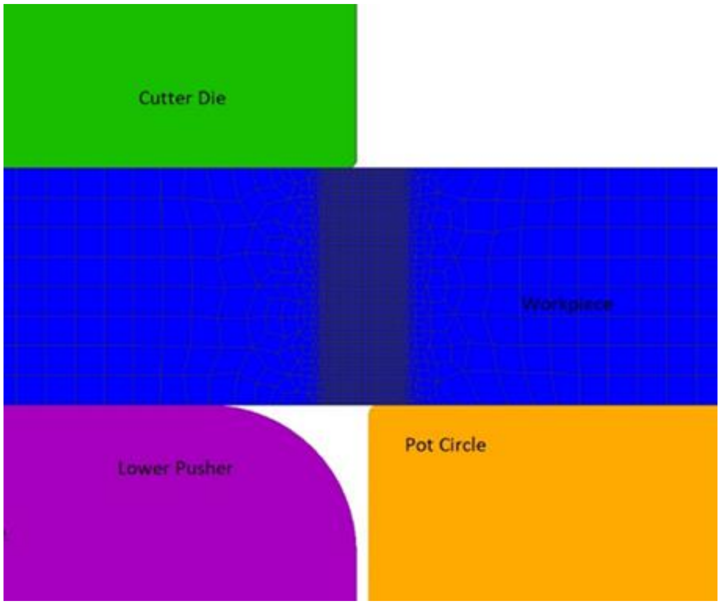

Figure 5. Workpiece Mesh Structure View

3. RESULTS AND DISCUSSION

In this study, numerical analyses were performed using Simufact Forming finite element program for the cutting and spinning operations of DC04 EN 10130 material. The parameters of the damage mechanism required for the simulation of the cutting process were determined. For sheet material, which is an automotive spare part product, the cutting clearance and ironing ratio of the die were decided. The technical drawing of the sheet metal part to be produced is shown in figure 6.

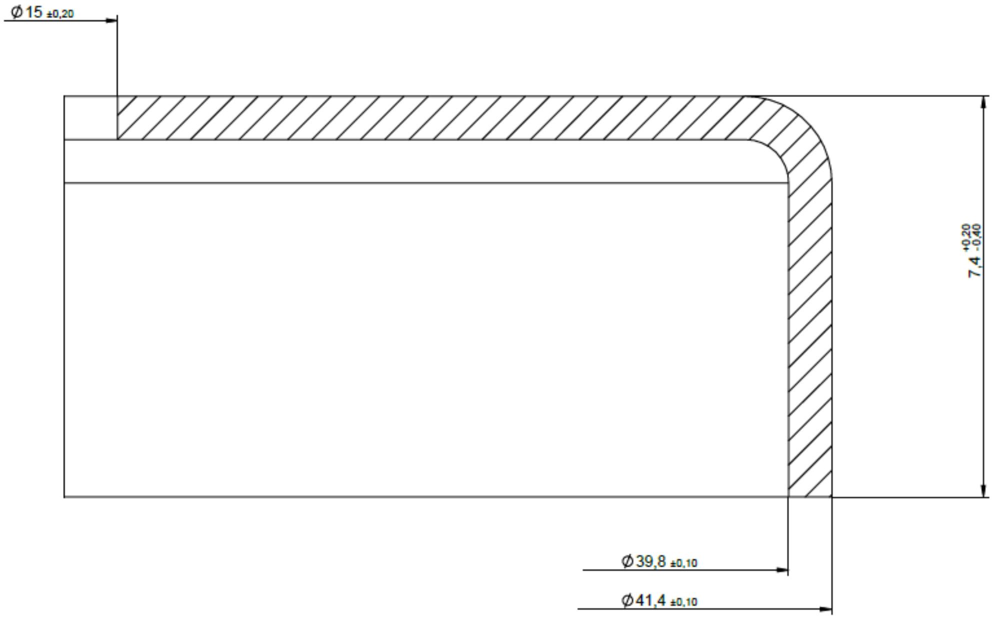

Figure 6. Technical Drawing

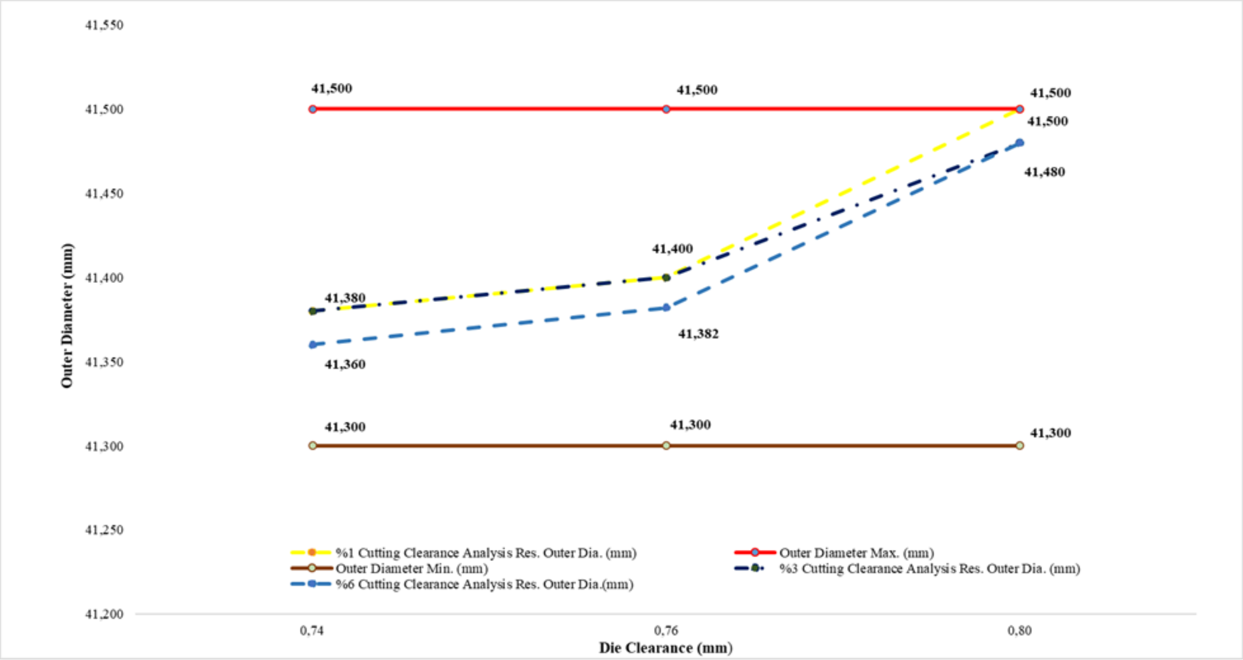

Figure 7. Outer Diameter Dimensions According to Cutting and Die Clearance

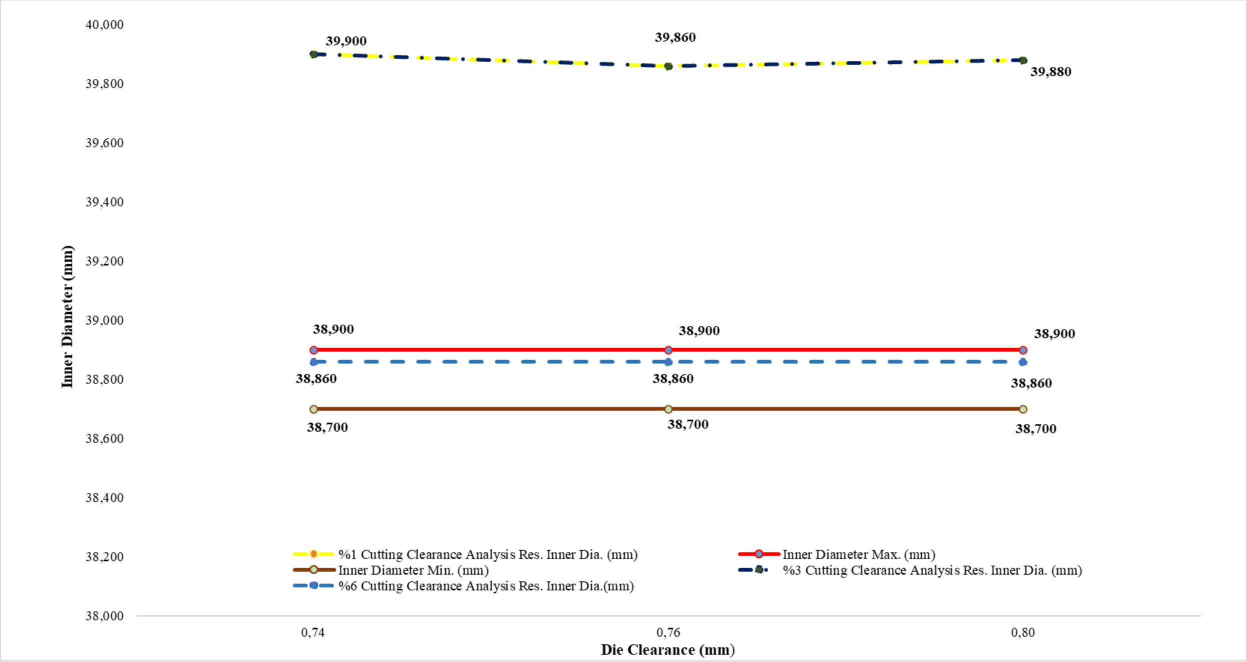

Figure 8. Inner Diameter Dimensions According to Cutting and Die Clearance

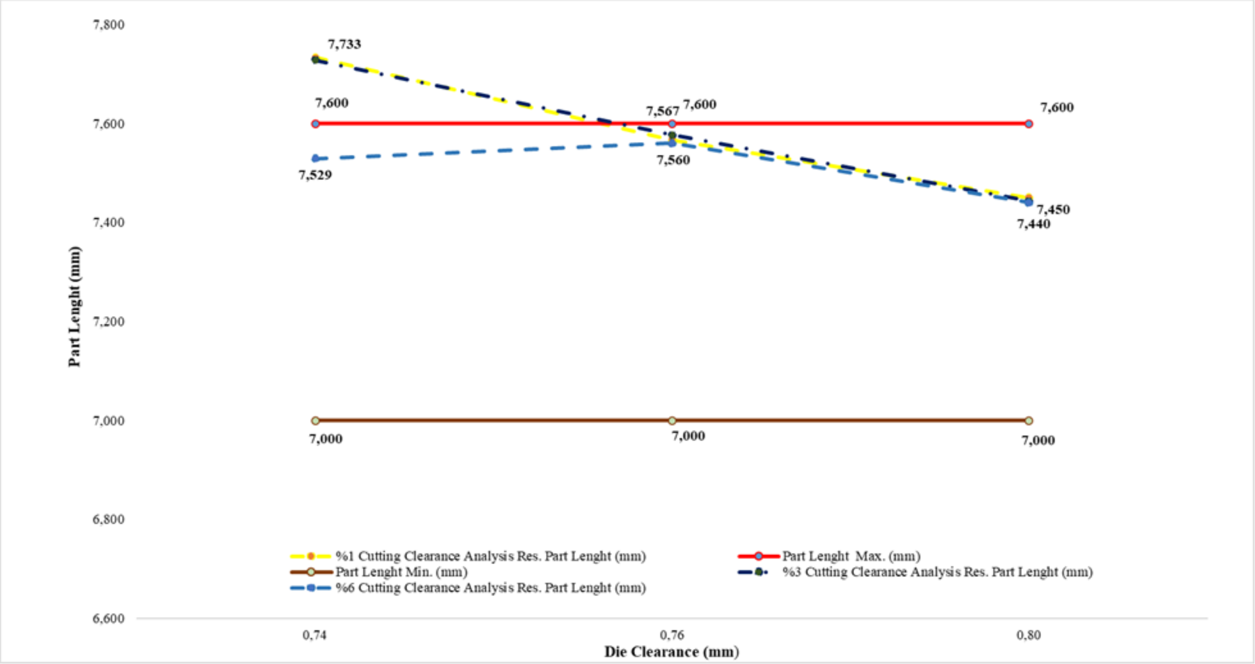

Figure 9. Part Length According to Cutting and Die Clearance

According to the obtained results from the finite element simulations, the critical regions of the formed part are measured and compared with the technical drawing measurements. As can be seen from the fig.7, the predicted outer diameter of the formed part is compatible with the dimensional tolerances of the technical drawing. However, for the inner diameter and the part length predictions, among the studied cases, 7.5% ironing rate and 6% cutting clearance is only satisfactory with desired geometry.

Besides the geometrical compatibility of the simulation, burr formation and cutting surface features on the cutting region are also investigated in this study. Most of the original part manufacturers aims to have limited burrs on their parts and these expectations enforce the part and die designers. In Fig 10. the cutting surface structure are depicted for the 7.5% ironing rate and 6% cutting clearance. In addition, the related features for other conditions are also tabulated in Table 3.

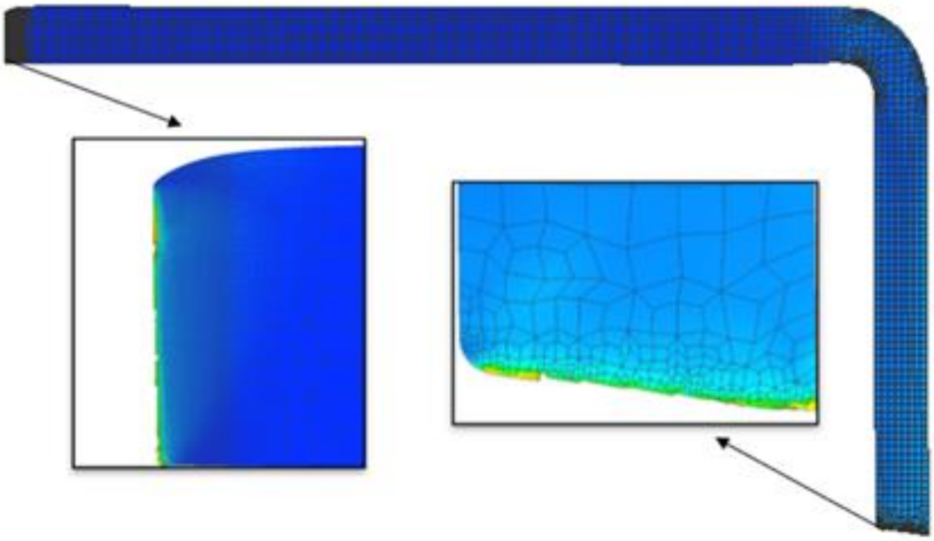

Figure 10. Cutting Surface

Table 3. Cutting Surface Angles

Cutting Clearance	**Die Clearance**		
	%7.5 Die Clearance	**%3 Die Clearance**	**%0 Die Clearance**
%1 **Cutting Clearance**	5.530°	7.860°	9.389°
%3 **Cutting Clearance**	5.180°	7.250°	9.178°
%6 **Cutting Clearance**	4.632°	6.894°	8.996°

As can be seen from the table, the angle on the cutting surface increases with Die Clearance which is related with the ironing effect, and decreases with the Cutting clearance. For all ironing conditions, the angle of the cutting surface has the minimum value for the 6% cutting clearance. The manufactured dies according to the aforementioned dimensions of the tools give good results with the simulations. The experimentally manufactured parts' cutting surfaces for %7.5 Die clearance and 6% Cutting clearance has 4.42° wall angle. The simulation results show well agreement with the experimental results.

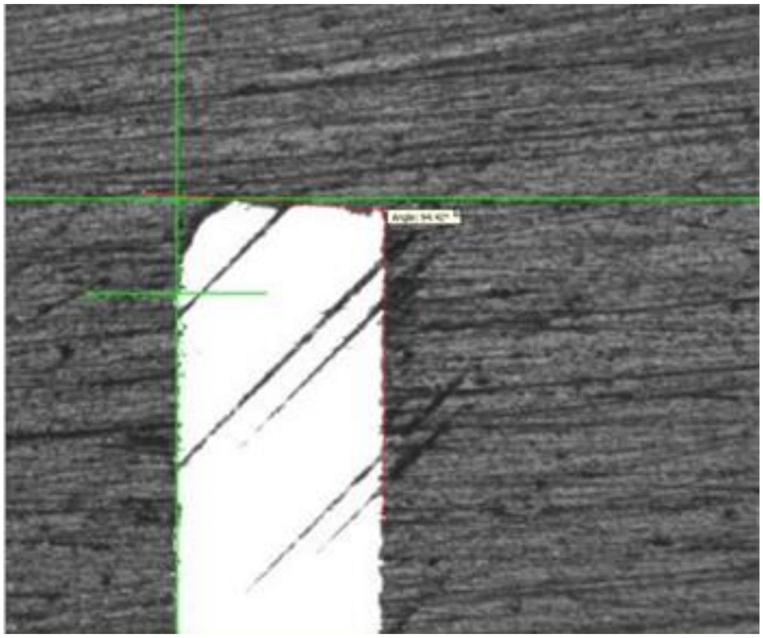

Figure 11. Wall Angle

3. CONCLUSIONS

In this study, DC04 EN10130 cold rolled steel material, which has a very important place for the automotive industry, was used. In the studies, 3 different cutting and spinning operations of DC EN10130 cold rolled steel material were carried out and its geometrical measurements were examined. The simulation of the cutting and spinning operations of the sheet material was analyzed using the Sheet Metal Forming module of the MSC Simufact program. Consequently, the following results have been accomplished:

- The cutting angle of the produced sheet material was found to be 4.42°. When the analysis of the die system with 0.74 mm spinning and 6% cutting gap was examined, an angle value of 4.63° was obtained. In this way, 95.2% accuracy was obtained with the analysis program.
- When the analysis of the die system, which has 7.5% spinning and 6% cutting clearance, is examined, it has remained within geometric tolerances in terms of inner diameter, outer diameter and length.
- It has been determined that as the cutting gap increases, the cutting surface angle decreases.
- It has been observed that the inner diameter values increase as the cutting clearance decreases.

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