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Experimental investigation of the deep drawing parameters of stainless-steel wire mesh structures

Paslanmaz çelik tel örgü yapıların derin çekme parametrelerinin deneysel incelemesi

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Abstract

The increasing use of wire mesh structures in industrial applications has led to a surge of interest in the forming methods of these materials. This paper investigates the practicality of the deep drawing method in shaping wire mesh structures with different weaving types and meshes. The study found that the forming ability of wire meshes with twill weave type is superior to that of plain weaves, and the setting direction directly affects the forming quality. Increasing mesh was found to decrease the formability of the material. Furthermore, experiments with different punch geometries revealed that circular punches with a 5 mm tip radius yielded superior forming performance compared to square and small radius punches. Additionally, it was observed that geometric forms added to the blank holder negatively affected the forming of wire mesh textures, and the forming ability decreased with increasing drawing depth.

Keywords: Deep drawing, stainless steel wire, wire mesh, formability

Öz

Endüstriyel uygulamalarda tel örgü yapıların kullanımı artmaktadır, dolayısıyla bu tür yapıların şekillendirme yöntemlerine olan ilginin artmasına neden olmuştur. Bu çalışma, farklı dokuma türleri ve sıklığına sahip tel örgü yapıların şekillendirilmesinde derin çekme yönteminin uygulanabilirliğini incelemektedir. Çalışma, dimi dokuma türü tel örgülerin şekillendirme kabiliyetinin düz dokumalardan daha üstün olduğunu ve kesme yönünün şekillendirme kalitesini doğrudan etkilediğini ortaya koymuştur. Dokuma sıklığının artmasının malzemenin şekillendirilebilirliğini azalttığı bulunmuştur. Ayrıca, farklı zımba geometrileriyle yapılan deneyler, 5 mm uç yarıçaplı dairesel zımbaların kare ve küçük yarıçaplı zımbalara kıyasla üstün şekillendirme performansı gösterdiğini ortaya koymuştur. Ek olarak, baskı plakasına eklenen geometrik formların tel örgü dokularının şekillendirilmesini olumsuz etkilediği ve şekillendirme kabiliyetinin çekme derinliğinin artmasıyla azaldığı gözlemlenmiştir.

Anahtar kelimeler: Derin çekme, paslanmaz çelik tel, tel örgü, şekillendirilebilirlik

1 Introduction

Wire mesh textures, 2D or 3D lattice structures, are formed by bonding two or more metal wires using various techniques such as weaving or knitting [1, 2]. These textures are instrumental in industrial applications across several sectors, including agriculture, automotive, textile, and paper [3, 4]. However, their primary role is in filtration and separation processes, where they effectively achieve specified pulp levels, particularly in wastewater treatment plants, petrochemical industries, and beverage production [5, 6]. Depending on the application, woven wire cloth can sometimes be used directly without shaping, while in other cases, it is necessary to mold the wire structure into the desired form [7]. Deep drawing is one of the most common methods for shaping wire mesh. This essential manufacturing process is widely employed to create cylindrical parts from sheet metal. The quality of the components produced through deep drawing varies based on several parameters, including punch geometry [8], die geometry [9], drawing depth [10], and die material [11]. These factors directly influence the formability of the parts generated by the deep drawing process.

The deep drawing process, a topic of significant importance, has been extensively examined in literature studies. Gotoh et al. investigated wire mesh structures and demonstrated that square punch geometries exhibit superior formability compared to circular ones, as indicated by higher limiting drawing ratios (LDR) [12]. Pushkar et al. emphasized the significance of temperature, noting that increased temperature enhances formability and reduces the required punch force [13]. Chandra and Geeta highlighted frictional forces between the die and workpiece as crucial factors affecting surface quality and thickness distribution [14]. Further, Rashmi and Geeta identified that the punch tip radius must exceed three times the die clearance to avoid failure, noting that insufficient blank holder forces could result in wrinkling [15]. Padmanabhan et al. utilized the Taguchi method to compare deep drawing parameters, concluding that die radius substantially influences the process [16]. This conclusion aligns with Colgan and Monaghan, who ranked die radius as the most significant parameter, followed by punch tip radius, drawing depth, punch speed, blank holder force, and lubrication [17]. Supporting these findings, Kanttikar et al. found that increasing the die radius reduces equivalent stress and the necessary force for deep drawing [18]. Conversely, Reddy et al. highlighted blank holder force as the most critical parameter, with punch tip radius and die radius following in importance [19]. Gavas and Izciler underscored the importance of clearance between the blank holder and die, noting its significant impact on product quality [20].

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Despite numerous studies on deep drawing thin sheets, research specific to wire mesh fabrics remains limited. This study, which investigates critical parameters such as punch and blank holder geometry, drawing depth, and wire texture in the deep drawing process of AISI 304L stainless steel wire mesh fabrics, holds the potential to significantly advance our understanding and application of deep drawing processes.

2 Materials and Method

Wire mesh structures can be categorized into two distinct types: square and Dutch. In this comprehensive study, the focus was on the square-type mesh, which is denoted by the number of gaps per inch in its mesh structure. As the mesh size increases, the number of gaps per inch decreases, making the gaps smaller. The capacity to filter smaller particles is enhanced by higher mesh. The experimental setup, depicted in Figure 1, was utilized to conduct deep drawing tests at ambient temperature without the incorporation of oil. The setup was connected to a 100 tons hydraulic press, and a die cavity with a diameter of 0.6 mm was fabricated between the die and the blank holder. The present study investigated the impact of various parameters on the deep drawing capability, including wire mesh structure, punch geometry, blank holder geometry, and drawing depth. In order to measure the compressive force applied to the workpiece during the deep drawing process, load cells were placed at the four corners of the experimental setup. In addition to these load cells, a linear potentiometer was utilized in the mold setup. These instruments evaluated the compressive force acting on the workpiece at varying drawing depths.

Figure 1. Hydraulic press for deep drawing.

2.1 Wire Mesh Structure

Four specimens were manufactured with different mesh structures using AISI 304L austenitic stainless steel wires. The specimens feature plain and twill weaves, varying mesh sizes, and different setting types, as illustrated in Figure 2. Table 1 summarizes the four distinct wire mesh structures. Each wire mesh group underwent deep drawing tests repeated five times. It's important to note that the tests were conducted for every group under uniform conditions, using the same punch geometry, deep drawing depth, and blank holder geometry, ensuring the reliability of the results.

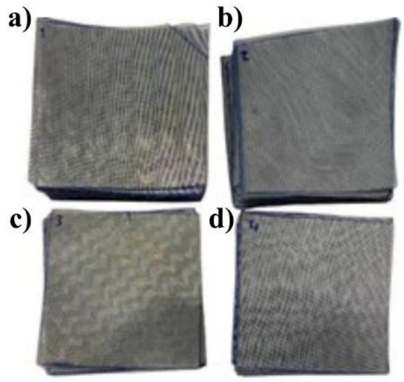

Figure 2. Four different groups of wire mesh specimen structures: a) T1, b) T2, c) T3, d) T4.

Table 1. Properties of various wire mesh specimen structures.

Wire Mesh Group	Weave Type	Mesh Size (μm)	Setting Type
T1	Plain	50	Parallel
T2	Twill	50	Parallel
T3	Plain	50	Diagonal
T4	Plain	60	Parallel

2.2 Punch Geometry

Seven different types of punches were manufactured from 5083 aluminum alloy. The characteristics of these punches are detailed in Table 2, and Figure 3 illustrates the punch types used in the deep drawing tests. The punch heights were kept constant at 50 mm, and widths were set at 24 mm. Different punch types were manufactured by varying the profile radii and shapes of the punches. A series of deep drawing processes was conducted to a depth of 24 mm using a 90 x 90 mm T2 group wire mesh in all experiments to investigate the impact of punch geometry. Each type of punch underwent five repeated deep drawing experiments to ensure the accuracy and reliability of the results. Figure 4 shows a schematic representation of the deep drawing tools.

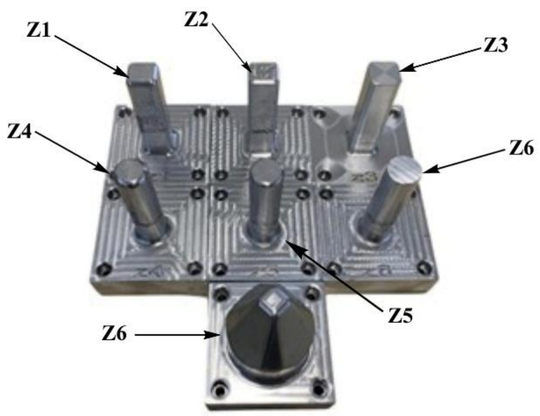

Figure 3. Seven different types of punch geometries.

Table 2. Properties of different punch types, all dimensions in mm.

Punch Group	Geometry	Punch Profile Radius (mm)
Z1	Square (24 x 24)	5
Z2		3
Z3		1
Z4	Circular (Ø24)	5
Z5		3
Z6		1
Z7	Special	5

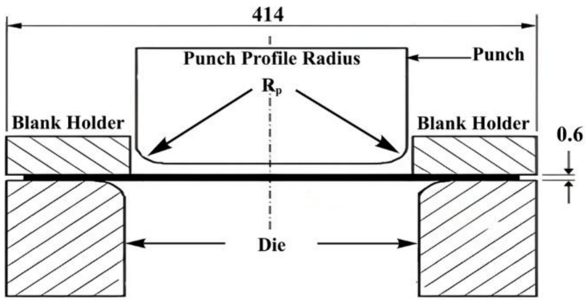

Figure 4. Schematic representation of drawing tools.

2.3 Blank Holder Geometry

Three different types of blank holders were manufactured from the same material as the punch for deep drawing. Circular shapes were added to the blank holder to control the drawing speed of the workpiece. The added shapes are shown in Figure 5. The blank holder types are listed in Table 3. In order to study the effect of the blank holder geometry, a 200 x 200 mm T2 group wire mesh with a depth of 24 mm was used with a Z3 punch in all deep drawing tests. The deep drawing tests were conducted 3 times for each blank holder geometry, ensuring the reliability of the test results.

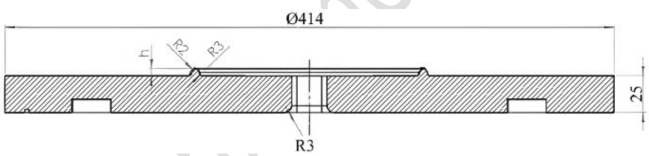

Figure 5. Geometry of the blank holder.

Table 3. Dimensions of different blank holders, all dimensions in mm.

Blank Holder Group	Type	R2	R3	h
B1	Unformed	-	-	-
B2	Formed	2.5	2.5	5
B3	Formed	1.25	1.25	2.5

2.4 Deep Drawing Depth

Experiments were conducted at three different depths of 30, 40, and 50 mm to investigate the effect of drawing depth on the deep drawing process. Z1 punch geometry and T2 wire mesh structure were used in all experiments. 100 mm x 100 mm, 120 mm x 120 mm, and 150 mm x 150 mm specimens were used for different drawing depths. The experiments were replicated 5 times for each group.

3 Results and Discussion

This study conducted a comprehensive investigation into the effect of wire mesh structure, punch geometry, blank holder geometry, and drawing depth parameters on deep drawing with four different experimental groups.

3.1 Wire Mesh Structure Analysis

Three different wires and two different setting directions were used to investigate the effect of changes in wire mesh structures on deep drawing. The properties of the specimens with different wire mesh structures are given in Table 1, and the force and displacement results obtained from deep drawing are presented in Figure 6. D1 indicates the experimental group, T1 indicates the wire mesh group, and the last number indicates the number of specimens.

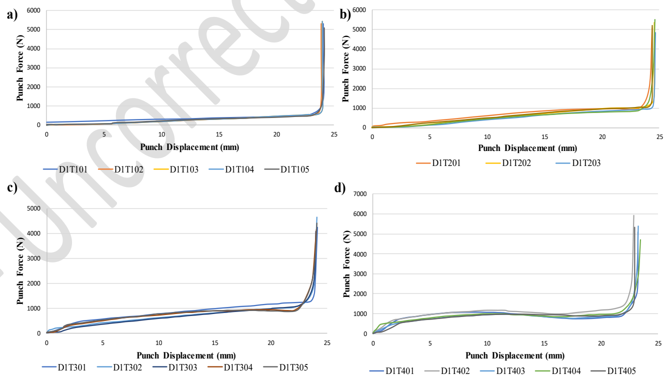

Figure 6. Punch force- displacement in various wire mesh structures; a) T1, b) T2, c) T3, d) T4 wire mesh structures.

After the deep drawing tests were implemented with the T1 group, the maximum recorded punch force was 5416.8 N, whereas this value was 5494 N in the T2 group. The alteration of the weave type in the wire mesh structure resulted in an increase of approximately 2% in the punch force, thereby indicating that the modification of the weave type does not induce a substantial change in terms of punch force. However, a notable enhancement in the deformation capacity of the wire mesh specimens was observed upon transitioning from a plain weave to a twill weave. In the T3 group, where the setting direction was modified from parallel to diagonal, it was evident that the wire's capacity to assume a shape was superior to that observed in the parallel wire mesh groups. Furthermore, it was ascertained that the displacement at the ends of the deep-drawn material exhibited significantly greater homogeneity when the wire setting direction was diagonal, suggesting a potential for improved product quality. The specimens from the T4 group, characterized by a denser mesh configuration, exhibited the highest levels of punching force. The results of the deep drawing process for each group are illustrated in Figure 7.

In the experimental investigation of four distinct wire meshes, a significant finding obtained. The deformation capacity of the T2 wire, surpassing that of the T1, T3, and T4 wires, was a key observation. This superior deformation capability of T2 wire, attributed to its weave structure that facilitates greater inter-wire mobility, is a crucial factor in enhancing the deep drawing performance of the wire mesh structure. This finding underscores the importance of understanding the weave structure in wire mesh design. A comparative analysis of the wire meshes' setting direction further revealed interesting insights. The diagonal-setting T3 wire, for instance, exhibited superior forming ability compared to the parallel-setting T1 wire. In the case of a diagonal setting direction, the tearing that forms at the outer boundaries of the specimen is found to be more homogeneous. Following a homogeneous shape change, the tear damage in the T3 wire is found to be lower than that in the T1 wire. The deep drawing performance of the T4 wire is found to be the lowest. As the mesh number increases, the tearing damage is more because the movement area of the unit wires decreases.

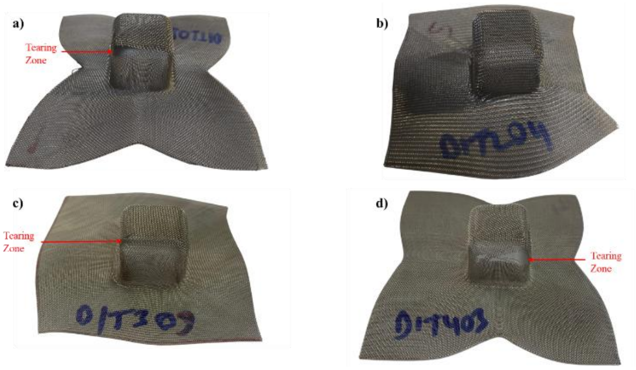

Figure 7. Deep drawing process results for various wire mesh structures; a) T1, b) T2, c) T3, d) T4 wire mesh structures.

3.2 Punch Geometry Analysis

A study examining seven different punch geometries was conducted to investigate the impact of punch geometry on the deep drawing process of wire mesh structures. The details of these punch geometries are provided in Table 2. The results for force and displacement from the deep drawing process using various punch geometries are illustrated in Figure 8. In this context, D2 represents the experimental group, Z1 refers to the punch group, and the last number indicates the specimen count. Additionally, Figure 9 shows the specimens produced through the deep drawing process with the different punch geometries.

The second experimental group's investigation findings, of significant importance, revealed that the maximum force recorded was 6082 N for the Z1 punch, which possessed the highest profile radius among the square punches. In contrast, the maximum punch force was recorded as 5543 N and 5395 N for the Z2 and Z3 punches, respectively, as the profile radius underwent a reduction. The results indicated that the maximum punch force diminished by approximately 12% as the profile radius diminished. Furthermore, the specimen exhibited tear damage in punch Z3, which possesses the lowest profile radius among the square geometry punches, as illustrated in Figure 9b. This significant finding suggests that the reduction in the punch profile radius, induced by the experiment with square punches, resulted in damage to the deep-drawn specimen. In the deep drawing process with punches with circular geometry, the maximum punch force was approximately similar to the square form. At the same time, there was a difference in the punch force-displacement curves. The force-displacement curves of punches with circular geometry have steeper slopes than those of punches with square geometry.

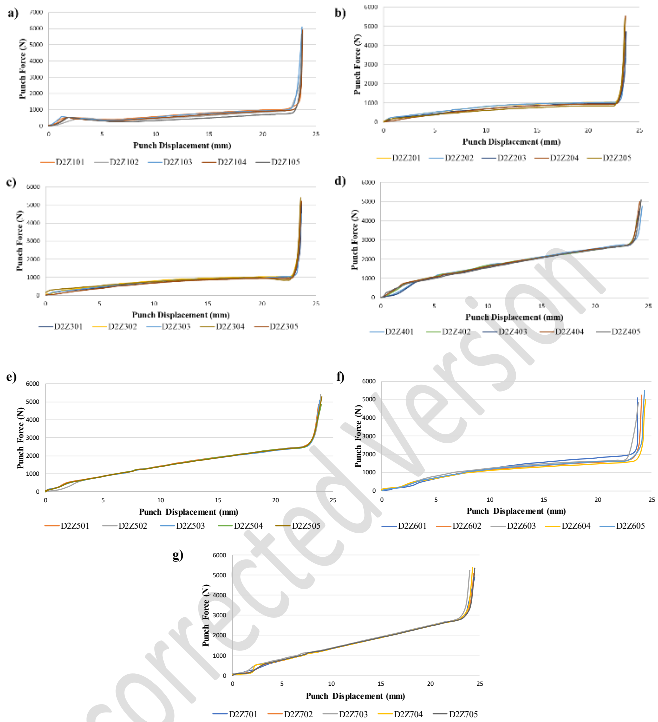

Figure 8. Punch force - displacement during deep drawing using various punch geometries; a) Z1, b) Z2, c) Z3, d) Z4, e) Z5, f) Z6, g) Z7 punch geometries.

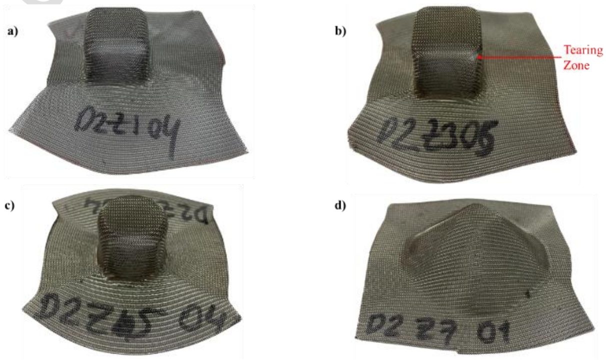

Figure 9. Deep drawing process results for various punch geometry; a) Z1, b) Z3, c) Z4, d) z7 punch geometries.

Furthermore, while the decrease in the profile radius in punches with square geometry caused tear damage, this did not occur in punches with circular geometry. This finding has significant practical implications, as it suggests that the deep drawing process can be executed with the specialized Z7 punch, which possesses angled walls and a high punch profile radius, without the risk of tear damage. The second experimental group's findings indicated that the circular-shaped punches' deep drawing capability surpassed that of the square-shaped punches. As the punch tip radius increased, the tear damage to the specimens diminished. The specimens obtained with the angular walls and large punch profile radius exhibited no tear damage and minimal wrinkling, further emphasizing the practical relevance of these findings.

3.3 Blank Holder Geometry Analysis

In the third experimental group, we investigated the effect of blank holder geometry on deep drawing using a blank holder with various geometries. The compressive force and displacement values applied to the wire were recorded for the three blank holders. The blank holders utilized in the experimental group and their properties were previously enumerated in Table 3. The punch force and displacement results obtained from the deep drawing process with various blank holders, presented in Figure 10, reveal significant insights into the deep drawing process.

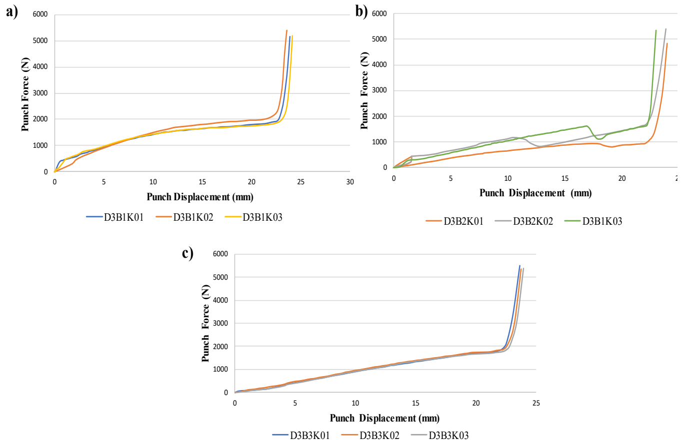

Figure 10. Punch force - displacement in deep drawing process using various blank holders; a) B1, b) B2, c) B3 blank holder geometries.

The maximum observed punch force during the deep drawing process was 5395 N for the unformed blank holder B1 and the formed blank holder B2 and 5493 N for the B3 formed geometry. These findings, which indicate the relatively insignificant effect of the blank holder geometry on the maximum punch force, are essential. However, it is directly related to the tear damage in the specimens obtained after the deep drawing. Minimal damage was observed in the unformed B1 blank holder specimens, while the shaped B2 and B3 blank holder geometries exhibited increased tear damage. In the third experimental group, where blank holder geometry was examined, it was observed that the height and depth values of the forms added to the blank holder increased, resulting in increased tear damage in the deep-drawn part. The presence of these forms hinders the movement of the workpiece during the deep drawing process, leading to the observed increase in tear damage. It was observed that the specimens obtained on the blank holder devoid of forms exhibited optimal performance. The samples obtained in this study are depicted in Figure 11.

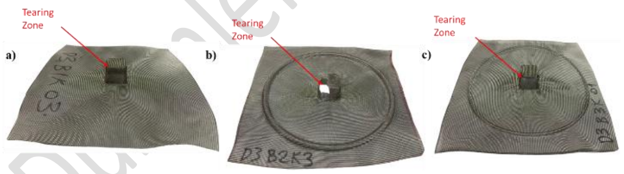

Figure 11. Results of the deep drawing process using different blank holder geometries; a) B1, b) B2, c) B3 blank holder geometries.

3.4 Drawing Depth Parameters Analysis

In the fourth experimental group, a diverse range of tests were performed: 30 mm, 40 mm, and 50 mm deep drawing tests. These tests were conducted to investigate the effect of drawing depth on deep drawing in wire mesh structures. The punch force and displacement results obtained from these varied tests with various drawing depths are presented in Figure 12.

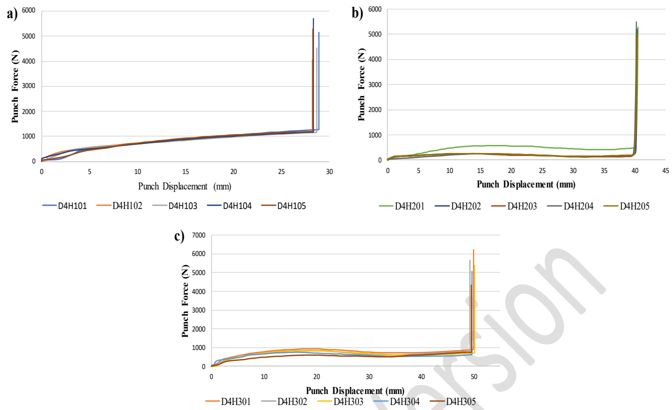

Figure 12. Punch force - displacement in the deep drawing process at various drawing depths; a) 30, b) 40, c) 50 mm drawing depths.

The study demonstrated a positive correlation between the maximum punch force and the drawing depth. The experiments revealed a 13.5% increase in maximum punch force with increased drawing depth. Figure 13 visually represents the specimens formed under various drawing depths.

Figure 13. Results of the deep drawing process using various drawing depths; a) 30, b) 40, c) 50 mm drawing depths.

An analysis of the punch force-displacement curves depicted in Figure 12 reveals a decline in blank holder force when the displacement value exceeds 30 mm. This phenomenon can be attributed to the onset of tearing damage to the deep-drawn workpiece. The findings from the fourth group of experiments, an important part of our research, which involved examining different drawing depths, indicate a decrease in the workpiece's deep drawing capability with increasing drawing depth. At drawing depths exceeding 30 mm, the tearing on the workpiece intensifies rapidly during the deep drawing process.

4 Conclusion

An experimental investigation was conducted to investigate the deep drawing process of stainless steel wire mesh structures. The investigation involved four types of wire structures, seven punches, three blank holder geometries, and three distinct drawing depths. The main conclusions are summarized below:

- The study's findings on the formability of wire mesh structures with different weave types, meshes, and setting directions have significant implications. For instance, the higher formability of twill weave wire mesh structures suggests a potential for improved performance in certain applications. The decrease in formability with increased mesh density highlights the need for careful design considerations. The influence of the setting direction on deep drawing behavior underscores the importance of process control in manufacturing.

- This study investigated the novel findings on the impact of punch profile radius and geometric form on the formability of wire mesh structures during the deep drawing process. By examining a range of punch geometries, we discovered that the formability of wire mesh structures increases with larger punch profile radii. However, tear damage is a concern at smaller radii. This study concludes that punches with circular and curved wall structures reduce wrinkle and tear damage more effectively than square punches.

• The experimental investigation thoroughly examined the impact of the blank holder on the drawing capability of wire mesh structures during the deep drawing process. The study, which utilized three distinct blank holders, revealed that circular forms led to tear damage by constraining the flow of wire mesh structures. Notably, the extent of damage was found to escalate with increasing form height. These findings suggest the suitability of flat forms of blank holders for wire mesh structures. However, it's important to bear in mind that the forms applied to the blank holder can enhance the formability of sheet metals while reducing that of wire mesh structures.

• An investigation was conducted to ascertain the effect of drawing depth on the deformability of wire mesh structures in the deep drawing process. Experiments were conducted at depths of 30, 40, and 50 mm. It was observed that the tear damage on the wire mesh structures increased in proportion to the increase in drawing depth. Consequently, the optimum drawing depth for wire meshes should be at most 30 mm when square punches with a 5 mm profile radius are utilized.

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6 Author contribution statements

In the scope of this study, the Author 1, in the assessment of obtained results, supplying the materials used and examining the results and the literature review; Author 2 in the formation of the idea, the assessment of obtained results and, examining the results; the Author3 the literature review, the spelling and checking the article in terms of content were contributed.

7 Ethics committee approval and conflict of interest statement

"There is no need to obtain permission from the ethics committee for the article prepared".

"There is no conflict of interest with any person / institution in the article prepared".

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