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Defects in Rotary Draw Bending and Their Effects on Formability

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Ovality
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Anahtar Kelimeler

Döner Çekme Bükme
Boru Şekillendirme
Geri Yaylanma
Ovalleşme
Kırışıklık

Graphical/Tabular Abstract (Grafik Özet)

Tube production by rotary drawing method is one of the most important pipe production methods preferred due to its production flexibility and easy availability of tools. Ovalization, springback, wrinkling and tearing are the most common defects in the pipes produced. Within the scope of this study, the effects of these errors on pipe bending were examined.

Figure A*: Tube bending machine / **Şekil A:**.Boru büküm makinesi*

Highlights (Önemli noktalar)

- *Errors affecting pipe bending, effects on the usability of the tube. / Boru bükümde etkili olan hatalar, borunun kullanılabilirliğini etkiler.*
- *Errors must be within certain limits / Hatalar belirli sınırlar içinde olmalıdır*
- *Rotary drawn tube bending method is the most preferred pipe bending method in the aviation field. / Döner çekme boru yöntemi havacılık alanında en çok tercih edilen boru büküm yöntemidir*

Aim (Amaç): *The aim of the study is to examine the errors that occur as a result of the production of pipe bending intervals and to reveal the causes of these errors / Çalışmanın amacı boru bükme aralıkları üretim sonrasında oluşan hataların incelenmesi ve bu hataların sebeplerinin ortaya çıkmasıdır.*

Originality (Özgünlük): *It was also examined in studies for titanium pipes. / Titanyum borular için çalışmalarda incelenmiştir.*

Results (Bulgular): *The outer side of bent tubes is exposed to tension and the inner side is exposed to pressure. Therefore, while the outer side of the tube becomes thinner, the inner side becomes thicker. When the rate of decrease in wall thickness is examined, it is seen that the rate of decrease in wall thickness is greater in tubes with the same wall thickness and in small pipe radii. It has been observed that as the wall thickness increases, the rate of decrease in wall thickness increases. It was also observed that as the bending angle increases, the increase in wall thickness increases. / Bükülmüş boruların dış tarafı gerilmeye, iç tarafı ise basınca maruz kalmaktadır. Bu nedenle, tüpün dış tarafı incelirken iç tarafı kalınlaşmaktadır. Et kalınlığının azalması oranı incelendiğinde, aynı et kalınlığına sahip borularda, küçük boru yarıçaplarında, et kalınlığında azalma oranı daha fazla olduğu görülmüştür. Et kalınlığı arttıkça, et kalınlığının azalma oranı arttığı görülmüştür. Büküm açısı arttıkça, et kalınlığındaki artışın arttığı da görülmüştür.*

Conclusion (Sonuç): *For the usability of the tubes, errors must remain within certain limits. / Boruların kullanılabilirliği için hataların belirli sınırlarda kalması gerekmektedir.*

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Abstract

Tube with different quantities and types; It can be described as a long and narrow cylinder with open ends, which carries liquids, gases and similar substances from one place to another. Tubes are used for advancements in sectors such as transportation, automobiles and aerospace. Aluminum, Inconel and titanium materials are decided according to the required needs in the design and production of tubes. There are different production methods to give permanent shape to the tubes. During tube bending operations, the feasibility of tube bending varies depending on the material type, bending angles, bending radius, tools and process. The tubes produced with a certain margin of defect. Some defects occur during and after production. Springback, ovality, breakage and tearing are among these defects. These defects may prevent the system to be replaced from flowing with the desired properties, as well as the installation of the produced tubes. The aviation and space fields, the production of tubes with high strength and complex geometries is critical. Errors that occur in the rotary draw bending process, one of these pipe bending methods, and the steps to prevent these errors are compiled and presented. It has been observed that as the bending angle increases, the back spring rate increases. In addition, it has been observed that ovulation increases when side pressure and stretching force increase

Döner Çekme Bükmedeki Kusurlar ve Şekillendirilebilirlik Üzerindeki Etkileri

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Öz

Farklı miktar ve tiplerde borular; Sıvıları, gazları ve benzeri maddeleri bir yerden başka bir yere taşıyan, uçları açık uzun ve dar bir silindir olarak tanımlanabilir. Borular, ulaşım, otomobil ve havacılık gibi sektörlerdeki gelişmeler için kullanılır. Boruların tasarımında ve üretiminde ihtiyaç duyulan ihtiyaçlara göre alüminyum, inconel ve titanyum malzemeler kararlaştırılır. Tüplere kalıcı şekil vermek için farklı üretim yöntemleri vardır. Boru bükme işlemleri sırasında, boru bükmenin uygulanabilirliği, malzeme türüne, bükme açılarına, bükme yarıçapına, takımlara ve işleme bağlı olarak değişir. Üretim sırasında ve sonrasında bazı kusurlar oluşur. Geri yaylanma, ovallik, kırılma ve yırtılma bu kusurlar arasındadır. Bu kusurlar, değiştirilecek sistemin istenilen özelliklerde akmasını ve üretilen tüplerin montajını engelleyebilir. Havacılık ve uzay alanlarında, yüksek mukavemetli ve karmaşık geometrilere sahip tüplerin üretimi kritik öneme sahiptir. Bu boru bükme yöntemlerinden biri olan döner çekme bükme işleminde oluşan hatalar ve bu hataların önlenmesi için atılması gereken adımlar derlenerek sunulmuştur. Bükülme açısı arttıkça arka yay oranının arttığı gözlemlenmiştir. Ayrıca yan basınç ve germe kuvveti arttığında yumurtlamanın arttığı gözlemlenmiştir.

1. INTRODUCTION (GİRİŞ)

Products made of sheet metal are widely used in our daily life in the medical, food, aircraft, automotive and aerospace industries. Sheet metal products shaped by various methods have become an indispensable part of daily life and industry. Many tube materials with different properties and functionality are passed through the manufacturing process with the help of several forming methods according to their intended use [1]. Tube products are widely used, especially in the transfer of liquids and gases. A tube is defined as a long and narrow cylinder with open ends, carrying liquids, gases and similar substances from one place to another, having a certain wall thickness. The tube bending process is a metal forming process to permanently shape

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tubes. Aluminum, Inconel and titanium alloys are the most preferred tube materials. In these processes, the bending angles and shapes of the tube's changes depending on the type of material. Especially because of the bending process of these materials, problems such springback, ovality, wrinkles and tearing are observed. Ovality and springback cause the installation of parts to become difficult or impossible. Titanium alloys stand out in the field for aerospace due to their lightness and strength properties [2].

Titanium is a material that is difficult to manufacture due to its low thermal conductivity and high strength properties. Titanium is used in different industrial fields (aerospace, defense, medical, energy, etc.) are preferred because of these characteristics [3]. Titanium tubes are used for transporting fluids in the aerospace and aviation sectors due to their high strength, high corrosion resistance, light weight, they are preferred in the aerospace sector because they allow hydraulic and fuel systems to operate at high pressures and high flows. Reducing stress in hydraulic transport systems, the Ti-3Al–2.5V tube improves the overall performance of advanced aircraft and spacecraft due to its unique high specific strength. Tube bending process, is carried out manually controlled by hydraulic, pneumatic, electro-mechanical methods or on CNC machines as in sheet metal forming processes [4]. In the titanium tube bending process, rotary pull bending process is preferred in the aerospace field [5]. Since the placement of fluid-carrying tubes in airplanes and helicopters requires installation in narrow and small areas, there is a need for small bending angles and small bending radius. However, titanium material has high strength, limited elongation at room temperature, due to high wall factor ratios, it is more difficult to shape than other materials [2]. Therefore, during production, various defects are encountered, as in sheet metal processes. During the production of titanium tubes or after the completion of production, problems such springback, ovality, wrinkling, tearing, reduction in wall thickness are seen in tubes. Springback occurs because the elastic deformation that occurs in the part during production wants to return the part to its previous state, in the installation application, it can prevent the tube from being assembled with the corresponding tube [6]. Ovality of the tube is a problem of deterioration of the circularity of the tube, and this prevents the flow of the fluid at the desired flow rate and pressure. Tearing and wrinkling caused during production cause the produced tube to be unusable. Problems encountered during production create problems in the installation or use of tubes. As a result of these reasons, it is stated in the literature that the production parameters of tubes pose installation difficulties. Studies on the bending ability of titanium tubes. It is observed that surface and wall thickness errors increase on the material depending on the difficulty of the material and the process. It is emphasized in the literature that the studies that will be carried out in this context will provide less erroneous production on the process. In this study, the errors and solutions contained in the literature are presente

2. TUBE BENDING PROCESS (BORU BÜKÜM METODU)

Tube bending process is carried out manually or on CNC machines, like sheet metal forming process, which use pneumatic, electro-mechanical or hydraulic methods. Rotary draw bending process is preferred in the aviation and aerospace industries.

2.1. Hydroform (Hidroform)

The tube hydroforming process allows the production of parts with variable geometries using fluid pressure. In the process, after the molds are closed on the part, the fluid pressure increases and axial load is applied to both sides, allowing the material to take the desired shape [6].

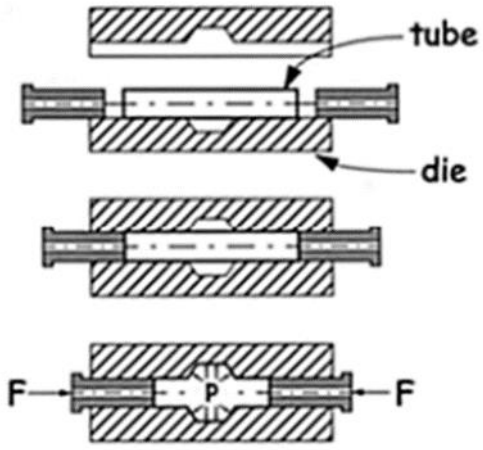


Figure 1. Hydroform tube bending process [6] (Hidrofom boru büküm yöntemi)

2.2 Three Roll Bending Process (Üç Toplu Büküm Yöntemi)

Three-Roll Bending uses three rollers arranged in a triangular configuration. The metal is passed

between the rollers, which apply pressure and cause the material to bend [7].

There are 2 different bending rolls on the bench: the bending roll and the adjustment roll. While the bending roller serves as a support to transmit the bending moment and lateral force to the work piece, the rear holding roller prevents dents from forming on the sides of the tube and ensures that the tube remains stable during the bending process. The adjusting roll can be rotated around the center of the bending roll or moved by turning it in the radial direction [8].

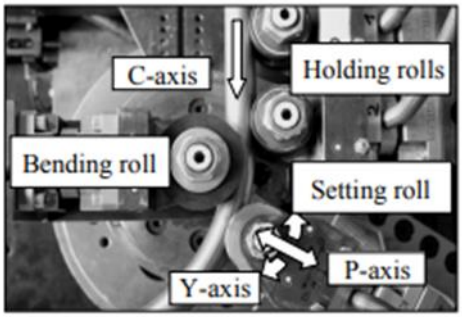


Figure 2. Three roll bending tube bending process [8] (Üç toplu büküm yöntemi)

2.3. Push Method (İtme Yöntemi)

The tube is produced with the pushing method places in the mold containing a mold and piston. To ensure that tube takes shape, it is pushed into the tool with axial load. Since the tool has the desired geometry of tube, production is completed.

The most important factors affecting the process are internal pressure, material and friction coefficient of the tube internal pressure is important to maintain its diameter [9].

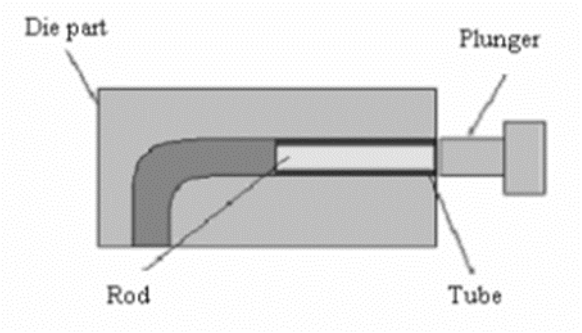


Figure 3. Push method tube bending process [9] (İtme yöntemi ile boru büküm)

2.4. Rotary Draw Bending (Döner Çekme Yöntemi)

The rotary pull bending method is a production method that can be produce precisely and is cost-effective for tubes with small bending diameters and thin wall thicknesses [5]. It is a precision production method for tubes with a diameter-to-wall thickness ratio of less than 20, which is increasingly used in different industries such as aviation and automobiles. In the rotary drawing method, bending die, clamp die, pressure die, wiper die and mandrel tools are used. Precise production can be made with defects such as thinning and wrinkling within the allowed wall thickness [10].

3.TOOLS IN ROTARY DRAW BENDING (DÖNER ÇEKME YÖNTEMİNDE KULLANILAN TAKIMLAR)

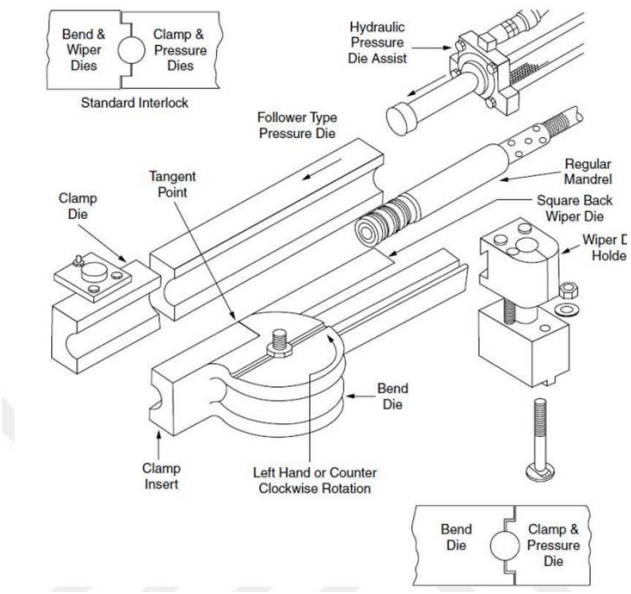


Figure 4. Rotary draw bending tools [11](Döner çekme yönteminde kullanılan borular)

3.1. Clamp Die (Kelepçe Kalıbı)

The role of the clamp die is to apply pressure between the tube and the clamping part of the bending die to hold the tube tightly during bending. For successful bending, the tube must be held securely [12].

3.2. Pressure Die (Basınç Kalıbı)

The pressure die moves with the tube and determines the bend point. Pressure dies are generally following the tube around the bend. There are times when the pressure pattern remains static and does not move with the tube [13].

3.3. Mandrel (Malafa)

Mandrel bending is a device used in the rotary drawing method, which is a solid mandrel shaft with up to five-piece, annular balls, slightly smaller than the inner diameter of the tube. It is placed inside the tube to provide internal support during bending. Placing a mandrel inside the tube prevents damage such as deflect, collapse, and tearing, and allows the ovality of the part to be controlled in terms of production [14].

4.DEFECTS IN TUBE BENDING(BÜKÜMDE OLUŞAN HATALAR)

Some production defects may be encountered during and after tube bending. While some defects can be controlled, some are inevitable. Defects encountered in the tube bending process are: springback, ovality, wrinkling and breakage. Some defects that occur do not prevent the use of the produced part, but the defects that occur must be within certain tolerance ranges.

4.1. Springback (Geri Yaylanma)

Springback is occurs at the end of each bend, which is a small geometric change on the material due to the release that occurs after the tools of our tube bending machine are opened. All this is normal, every material, every thickness, every radius has a different springback rate. Of course, springback can be calculated and it is very important to do this in order to make a series of bends that are all the same [15].

4.2. Ovality (Ovalleşme)

One of the most common problems in tube production is the ovality problem. This problem occurs in two different ways: the shape of the section changes or the wall thickness changes.

In the cross-section of the tube, the wall thickness on the outside decreases because it is exposed to tensile stress, and the wall thickness on the inside increases because it is exposed to compressive stress [15].

4.3. Wrinkle (Kırışıklık)

The area where wrinkles occur is the area where the continuity of the walls is disrupted in the bend radius region. The wrinkle is caused by the compressive forces that occur during bending of the tube. In tubes with large diameters and thin wall thickness, during the tube bending process, if the process parameters are not appropriate, it may cause wrinkling [16].

4.4. Break (Kırılma)

Breaks occur in the bent part of the tube. The outer surface of the tube in the bent area is exposed to tensile force during bending. When the tensile stress occurring on the outer surface exceeds the tensile stress value of the material, the material begins to yield and then breaks and gets damaged [17].

5.DEFECTS IN ROTARY DRAW BENDING AND EFFECTS(DÖNER ÇEKME YÖNREMİNDE OLUŞAN HATALAR VE ETKİLERİ)

Explanations of the studies conducted within the scope of the literature research are examined below.

Table 1. Literature research (Literatür araştırması)

Reference No	Writer	Year	Material	Variables	Variable to examine		Conclusion
18	Z.Q. Yiang, H. yang	2010	TA818M Titanium	Springback	Bending Angle (°)	30/60/90/120	If bending angle increase, springback angle increase. If Young modulus increase, springback angle decrease
					Young's modulus(E/Gpa)	85/95/105	
19	Daxin E, Yafei Liu	2010	1Cr18Ni19Ti Stainless Steel	Springback	R/d (Bending Radius/Tube Diameter)	2.5/3/3.5/4/4.25/5	If R/d increase, springback angle increase
20	Ufuk Penekli	2008	Aluminum 6010	Wall Thickness Change (Ovality)	Bend Radius(mm)	100/110/120/130	If the bending angle increase, the wall thinning in the bent beam decrease. If the bending angle and wall thickness increase, springback angle is also increase
				Springback	Wall Thickness(mm)	1/2/3	
21	Li Chunfeng, Yang Yuying	1998	LY12M	Ovality	Side Press(N/mm)	50/100/150/200/250/300	If the side press increases, ovality decrease
					Stretching Force (Mpa)	5/10/15/20/25/30	If the stretching force increase, ovality decrease
22	Li Chunfeng, Yang He	2008	Al 5052 O	Tube Wall Thinning (Ovality)	Bending Velocity (°) /s	3.80/4.51/5.86	After 3.90(°) /s bending velocity, tube easily crack. If mandrel extension length increase, wall thinning rate increase. If the friction decreases, wrinkling decrease.
					Mandrel Extension Length (mm)	10/15/19	
				Wrinkling	Friction	Small Friction, Large Friction	
23	A. Mentella M.Strano	2011	Cu-DHP	Ovality	OD (mm)	18-16	Ovality is highest at 45°. When the angle increases from 45° to 90°, ovality decrease.
					Thickness (mm)	1-0.9	

					Bending Radius (mm)	27-24	
24	H. yang, M. Zhan	2010	Al 5052 O 1Cr18Ni19Ti Stainless Steel	Tube Wall Thinning (Ovality)	R/d (Bending Radius/Tube Diameter) Clamp Die End to Tangent Point (°)	1.5/2.0 0° to 90°	Up to 45°, wall thinning increase, after 45° wall thinning degree decrease linearly. When R/d rate decreases, wall thinning degree increase
25	Tang, N. C.	2000	-	Stress Wall Thichkness Change	-	-	Within the scope of this study, a cumulative composition is created for errors occurring in tube bending.
26	Li, Jie	2023	304L	Wall Thickness Change (Ovality)	Diameter adjustable mandrel in small and big diameters. Inner Diameter	I.D.:40-56 mm	A larger DAM diameter results in having a smaller ovalization.
27	Borchmen, Linda	2020	1.4301	Wrinkle	Axis Stiffness	1-10-100-1000	Low Axial stiffnesses correspond to large axial displacements when force is applied, resulting in more wrinkle formation.
28	Naderi, Gholamali	2023	Corrosion Resistent alloy fitted with outer carbon steel pipe	Wall Thickness Change (Ovality)	Diameter adjustable mandrel in different size	0.96-0.99 Di.	Diameter adjustable mandrel work better in bigger diamters and it has a positive effect on ovality.

For the springback result, it was seen that the springback depends on the material properties of the tube, the bending angle and especially their connection effects. It has been seen that the interactions of these parameters with the bending angle, as well as the Young's modulus, yield stress, strain compaction coefficient and thickness anisotropy exponent have a significant effect on the backward flexural angle by Yang. Springback is divided into 3 different categories. The angular springback, bending radius springback and the cross-sectionally springback. The angular springback and cross-sectionally springback increase as the bending angle increases [18]. Also, if young modulus increase, springback angle decrease. it has been observed that as the ratio of

diameter to wall thickness increases, angular springback and cross-sectionally springback values increase [19]. Also, it has been observed by Penekli, as the bending angle increases, the springback angle increases linearly and the wall thickness increase, the springback also increase [20].

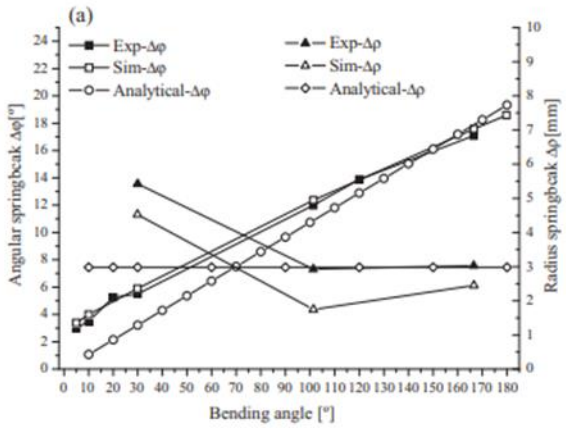
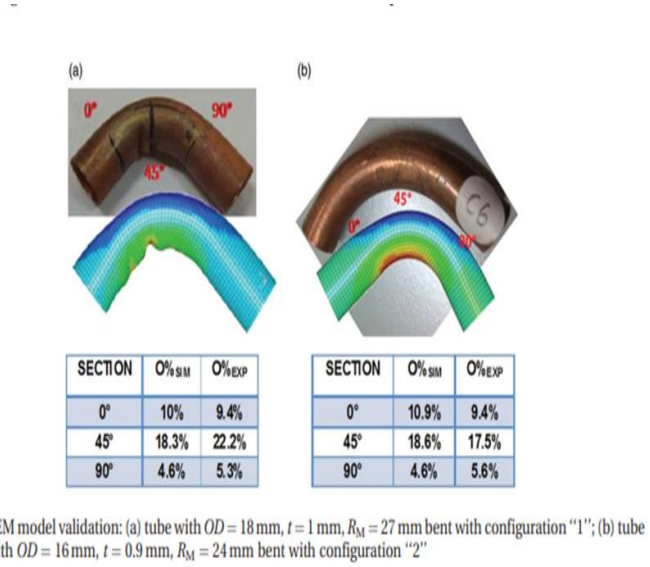


Figure 5. Angular and radius springback change depending on angle [2] (Yarıçap ve açısal geri yaylanmanın açıya göre değişimi)

Also, the research made by Song (Figure 5), it is shown by experimental and simulation results, angular springback increase when the bending angle increase. For radius springback, maximum springback occurs at 40°, after 40° angular springback value decrease [2].

For the ovality result, Ovality of the tube is a problem of deterioration of the circularity of the tube, and this prevents the flow of the fluid at the desired flow rate and pressure [23]. The study made by Penekli stated, the wall thinning is expected at the outer side, wall thickening is expected at the inner side. Also, when bending radius increase, the wall thinning in the bent area also decrease [20]. At the end of the study conducted by Chufeng, it was seen that the value of cross-sectional ovality decreases with the increase of side pressure and stretching force. In addition, it has been observed that the cross-sectional ovality decreases in the process of rotating tensile bending [21]. Also found by Chunfeng, if mandrel extension length increase, wall thinning rate increase [22].



SECTION	O%SIM	O%EXP
0°	10%	9.4%
45°	18.3%	22.2%
90°	4.6%	5.3%

SECTION	O%SIM	O%EXP
0°	10.9%	9.4%
45°	18.6%	17.5%
90°	4.6%	5.6%

FEM model validation: (a) tube with $OD = 18$ mm, $t = 1$ mm, $R_M = 27$ mm bent with configuration "1"; (b) tube with $OD = 16$ mm, $t = 0.9$ mm, $R_M = 24$ mm bent with configuration "2"

Figure 6. Cooper tube ovality change depending on angle [23] (Bakır boru ovalliği açıya bağlı olarak değişimi)

The research made by Mentella (Figure 3), it is found, bending angle increase 0° to 45°, ovality increase and maximum ovality occurs at 45° [23].

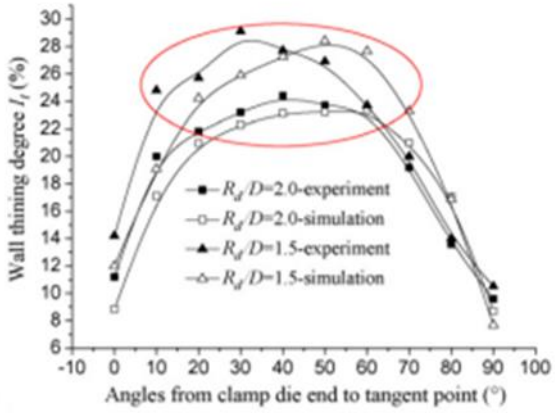


Figure 7. Wall thinning degree change depending on clamp die end to tangent point [24] (Kelepçe kalıp ucu ile teğet noktası arasındaki duvar inceltme derecesi değişimi)

The research made by Young and friends (Figure 7), clamp die to tangent point degree increase, wall thinning degree increase until 45°, after 45° wall thinning degree decrease linearly [24]. For another research, Diameter adjustable mandrel use for ovality results It has been observed that a larger DAM diameter results in having a smaller ovalization but the thinning of the wall thickness increases [26]. Al so seen in different research, while better results are obtained for ovalization with

DAM, negative effects occur in the change in flesh thickness [28].

Wrinkling caused during production cause the produced tube to be unusable. it has been found by Yang that two different types of wrinkles are formed. Firstly, on the flat line in contact with the mandrel and wiper die, regional wrinkles were formed. Secondly, because of the clamp die sliding, the wrinkles formed by blocking the material flow. This situation can be eliminated by preventing the occurrence of slippage. Since the first situation will occur, it is appropriate to proceed as a result of the study, it was found that the friction between the pressure mold and the outer surface of the tube has a significant effect on the thinning of the tube wall. In same research, it has been found that as the amount of friction increases, the thrust force may increase, which may cause the inner surface of the tube to thicken and, accordingly, wrinkling may occur. As the amount of friction decreases, the risk of wrinkles decreases, but in this case, it can lead to thinning of the outer surface [22]. In another research, it has been shown that, when force is applied low axial stiffness's correspond to large axial displacements, resulting in more wrinkle formation [27].

6. CONCLUSIONS (SONUÇLAR)

- As a result of the studies, the ratio of diameter to wall thickness increases, springback angle values increase. Also, if the bending radius increase, springback angle increase. Using materials which has bigger Young modulus, it increases springback angle [25].

- For the ovality result, the value of section ovality decreases in the rotary drawing bending process when the number of reversals is three or more. The bending angle increased, the change in wall thickness increased. Increase of side pressure and tensile force can be used for cross-sectional ovality decrease.

- For wrinkle results, it has been found that two different types of wrinkles occur. Firstly, regional wrinkles formed in the straight line in contact with the mandrel and wiper die. Secondly, they are wrinkles that occur by blocking the material flow because of clamp die shifting. Additionally, it has been determined that as the amount of friction increases, the pushing force may increase, which may cause the inner surface of the tube to thicken, and wrinkling may occur accordingly. High pressure may be required to eliminate wrinkling. In such a case, relatively small values of internal pressure combined with axial tension can be used to eliminate wrinkling.

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DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

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AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Büşra İŞLER*:** She studied on the subject were examined and a general summary was prepared.

Konu hakkında yapılan çalışmalar inceledi ve genel bir özet hazırladı.

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CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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