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# A new process optimization of deep drawing part for sheet metal forming in automotive industry

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# A New Process Optimization of Deep Drawing Part for Sheet Metal Forming in Automotive Industry

## Highlights

- ❖ Stamping
- ❖ Deep Drawing
- ❖ Drawing Die
- ❖ Sheet Metal Forming
- ❖ Stamping die process optimization

## Graphical Abstract

The stamping line stoppage time related with tearing problems were reduced to the lowest level, at the end of the study.

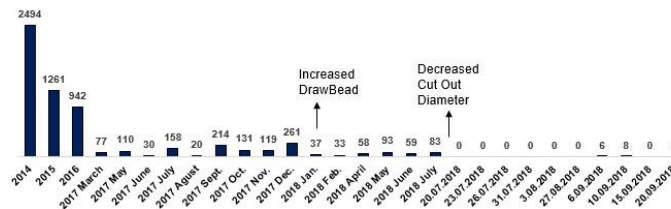


Figure. Line stoppage trend

## Aim

It is aimed to eliminate the tearing problem that occurs in the sheet metal forming process, which is a part of automotive production.

## Design & Methodology

Problem solving techniques were applied to determine the root causes of the problems and research was conducted for each root cause.

## Originality

In order to eliminate a problem in mass automotive production, experiments on the geometry of the blank sheet metal were made in the simulation environment and the most suitable one was tried under the conditions of mass production.

## Findings

A relationship/ratio was determined between the drawbead force and the blank sheet metal's cut-out geometries.

## Conclusion

According to the found ratio, a new type of blank sheet metal cut-out geometry was created and the problems were minimized by testing it under mass production conditions.

## Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

# A New Process Optimization of Deep Drawing Part for Sheet Metal Forming in Automotive Industry

*Araştırma Makalesi / Research Article*

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## ABSTRACT

Drawing die complexity is higher than conventional stamping operations, nowadays. It needs to decrease stamping die operation numbers for a part to reduce project budget consumption. Therefore, frequency of tearing, thinning, crack occurrence increase while this amendment. Force, blank cutting, blank location on the drawing die and process optimization were investigated to decrease tearing, thinning and crack occurrence in Transit bodyside inner panels which have over 110 mm. deep drawing process. Formability was improved at the end of this study. Thus production scrap, stoppage time of stamping line were decreased over 90%. This study was conducted at Ford Otosan.

**Keywords: Stamping, deep drawing, sheet metal forming, drawing die, stamping dies process optimization, press.**

## 1. INTRODUCTION

Production cost has increased because of new mobility systems such as self driving, electrification or driving assistance systems in the last 20 years in automotive industry [1-3]. So, new method and optimization systems are investigated by engineers and technicians to decrease budget of projects without reducing quality of final parts on main frame of cars [1]. Raw materials are the first key point of the production budget in automotive industry [3,4]. In these sense, stamping engineers reduced number of die for a part. There were five dies for conventional stamping methods before – if process has blank die, then there were six dies-, however nowadays stamping operations have four or less dies. That means, parts which have more complexity should be stamped in less operation dies.

Deep drawing process is the most important and complex method for automotive industry in terms of forming sheet metal which is used for reinforcement, body or skin panels [5]. Using of less stamping dies lead to increasing complexity on drawing dies. Generally second drawing operations are cancelled, because of that cutting/punching operations are not preferred during drawing operations, when the number of dies decreased. Applying cutting/punching operation together with drawing operations has already lots of problem related with panel surface quality such as burr mark on panel surface, burr on trim edges or deformation on cutting/punching areas because of drawing [6,7].

Therefore a part should be shaped in single drawing. But if the part has over 110 mm. depth, it will have crack or thinning probably because of single drawing die constraint related with general stamping regulations. Parts which have over 110 mm. depth were shaped in double drawing die operation in the conventional method before, but now it has to be shaped in single drawing die operation to reduce project budget as mentioned above.

Body side inner panels that have over 110 mm. depth were investigated in terms of drawbead force, blank cutting, blank location on drawing die and general process optimization (ram force, cushion force etc.) to prevent tearing, thinning, wrinkles or insufficient surface tension. Blank holder force and friction of drawing die are first key points of sheet metal forming, according to lots of study [8]. According to some studies, another important factor as much as the die is the sheet material properties. Defining of the material's mechanic properties clearly and revealing them instantly is an important decision parameter for sheet metal forming. Zoesch et al. have detailed the methods to be used in the determination of these properties and referred to obtaining the material properties before forming in their studies [9]. Kakandikar et al. referred to the root cause points to be inspected in the elimination of shaping problems and they were examined lubrication and die radiuses [10].

Different problem solving methods were used to determine the root cause of problems in this study. The first one is fishbone diagram, the second one is cause and effect analysis (with customer expectations and scrap reasons), and the last one is design of experiment (DOE).

Five years data of mass production were used to decide problem to be studied, in order to prioritize the problems and to verify the conclusion of this study.

## 2. MATERIAL VE METHOD

This study was investigated and conducted to solve the shaping problems in automotive industry. Therefore first of all, line downtime data which was gathered since 2014 was investigated in order to decide which problem would be worked on. According to downtime data, the best development rates were achieved on rear door outer, small bodyside inner right hand side, high roof rear door outer, medium bodyside inner, small bodyside inner left hand side,

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respectively as shown in Table 1. However, according to the last year downtime data in Table 1, medium bodyside inner panel was seen as affecting the downtime much more comparing the last two panels. Hence, it was decided to work on medium bodyside inner panel.

Process Force; used die for the shaping of the part is not worked with cushion drive. Die is worked with gas spring. Gas spring pressure was checked before and after each production during this study, therefore process force is not key input.

**Table 1.** Downtime data according to panels (min).

	2014	2015	2016	2017	TOTAL	% Development rate after project launch
<b>Rear Door Outer</b>	6153	1911	1093	888	10045	<b>86</b>
<b>Small Bodyside Inner LH</b>	1573	2200	1774	902	6449	<b>42</b>
<b>Medium Bodyside Inner</b>	2494	1261	942	1342	6039	<b>46</b>
<b>Small Bodyside Inner</b>	881	1157	615	301	2954	<b>65</b>
<b>High Roof Rear Door Outer</b>	1393	562	343	720	3018	<b>48</b>

Tearing and thinning are on the top of downtime causes when investigated of bodyside inner panels problems according to downtime data shown in Table 2. Tearing and thinning problem are the first reason of scrap cost as well shown in Table 3. Fish-bone diagram was carried out to understand the reason of downtime and scrap cost shown in Figure 1.

Stroke per minute; different shaping speeds were investigated in this study, but there is no significant results were achieved. Mapping/Surface roughness; die surface mapping/roughness was inspected by eight different experts, it is reached a consensus that the mapping/roughness of die surface is correct.

**Table 2.** Downtime data of body side inner panel (min)

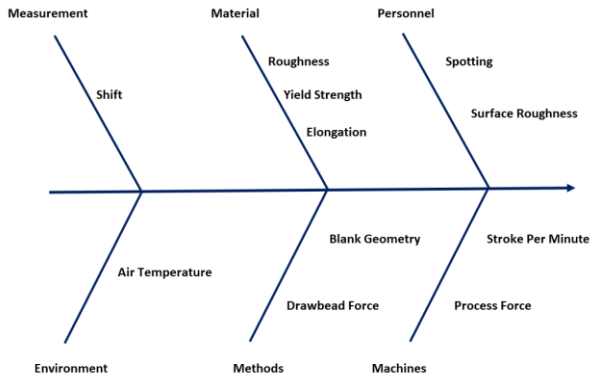
	2014	2015	2016	2017	TOTAL
<b>Tearing/Thinning</b>	1567	734	634	982	3917
<b>Wrinkles</b>	927	527	308	360	2122
<b>Dint Deng</b>	394	267	197	245	1103
<b>Dropping of Scrap Fail</b>	52	70	119	100	341
<b>Die Mark</b>	104	92	46	24	266

Possible causes of downtime and scrap cost were seen as tearing and thinning, according to Table 2. Wrinkle is reversible action for tearing and thinning [11-12]. So that wrinkle problem was written as third problem on cause and effect analysis, shown in Table 4.

Root cause analysis and investigation were performed to understand and verify the origin of problems, respectively. After defining possible causes with fish bone diagram, cause and effect analysis was performed by experienced technicians, engineers and managers with brainstorming method that shown in Table 4. Eleven different probabilities and possible outcomes were divided into problem modes as shown in Table 4. According to cause and effect analysis, roots of problem were understood as drawbead force and blank geometry, respectively. Other possible causes were eliminated because of;

Shifts and air temperature; the datas were gathered to understand root cause of problems during three shift in four years. Therefore, it was not in question if the problems arise from different shifts or different operators. In addition to that, stamping lines are fully automatic in Ford Otosan Kocaeli Plant, it is not depending on people' capability.

Sheet metal mechanical properties; there is no direct correlation between the variability of sheet metal mechanical properties and scrap ratio shown in Table 5, but the effects of mechanical properties can be investigated in further studies.



**Figure 1.** Fishbone diagram to understand of problem root cause

repeated in the stamping line to verify at the beginning of the blank geometry studies.



**Figure 2.** Tearing problem on cut-out

Tearing problem was prevented on around of the cut out thanks to cancellation of cut out, however tearing was

**Table 3.** Scrap cost according to defects (\$)

	2014	2015	2016	2017	TOTAL
<b>Tearing/Thinning</b>	5725	1613	1041	1158	9537
<b>Wrinkles</b>	2495	250	124	113	2983
<b>Dint Deng</b>	787	440	468	211	1907
<b>Other</b>	149	186	307	399	1041
<b>Surface Quality</b>	0	76	380	35	491

**Table 4.** Cause and effect analysis

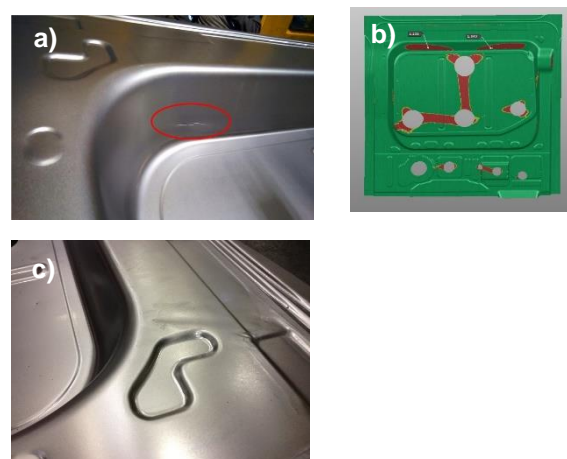
Rating of Importance to Customer (1=low, 3=medium, 9=high)		9	3	1	Total
		1	2	3	
		Tearing	Thinning	Wrinkles	
Input (1=low, 3=medium, 9=high)					
1	Yield Strength	9	3	9	<b>99</b>
2	Elongation	9	3	3	<b>93</b>
3	Roughness (Material)	9	9	1	<b>109</b>
4	Blank Geometry	9	9	9	<b>117</b>
5	DrawBead Force	9	9	9	<b>117</b>
6	Process Force	3	3	3	<b>39</b>
7	Stroke	1	1	1	<b>13</b>
8	Mapping	3	3	3	<b>39</b>
9	Roughnes (Die)	3	3	3	<b>39</b>
10	Shift	1	1	1	<b>13</b>
11	Air Temperature	1	1	1	<b>13</b>

observed on the wall of the part shown in Figure 3a and Figure 3b. Shim adjustments were applied on the drawing die to arrange sheet metal moving in order to prevent tearing problem on the wall. Moving of blank sheet was increased approximately 5 mm while adding shim to balance block shown in Figure 3c, this is why wrinkles were occurred. There was a direct relation between tearing and wrinkles shown in Figure 3c. When tearing problem is ok, then wrinkles are occurred; when wrinkle problem is ok, then tearing and splitting are occurred.

**2.1 Possible Problem Causes**

**2.1.1. Blank geometry**

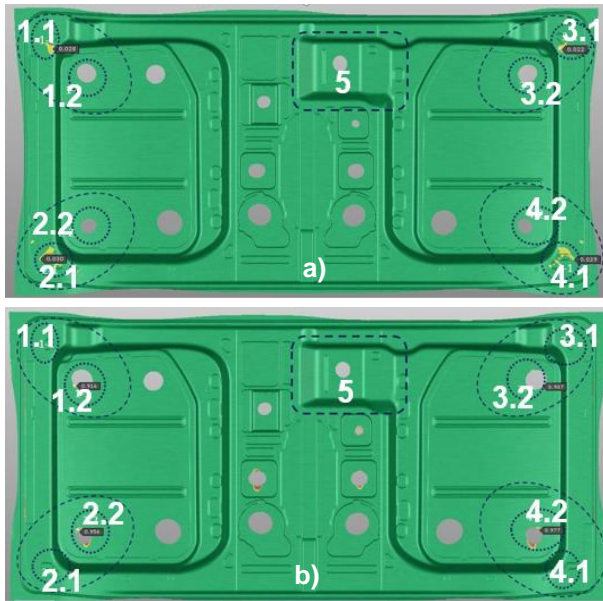
Tearing problem is generally observed on around of cut out shown in Figure 2a and Figure 2b. It was thought to cancel the cut out, accordingly experiments were made on simulation programs and then experiments were



**Figure 3.** Tearing problem on panel wall (a) and (b), wrinkle problem (c)

As a result, cancellation of cut out solved only wrinkles problems, but tearing, thinning and splitting are still matters. In that situation, it was decided to work with cut out, but not current cut out geometry. Tearing and wrinkles relations were investigated on simulation

program with cut outs and wrinkles results shown in Figure 4a. Possible tearing areas 1-2, 2-2, 3-2 and 4-2 are safe when possible wrinkles areas 1-1, 2-1, 3-1 and 4-1 are not safe in Figure 4a and Table 6.



**Figure 4.** Tearing (a) and wrinkle (b) relations.

Maximum failure results are shown in Figure 4b and Table 6. Possible wrinkles areas 1-1, 2-1, 3-1 and 4-1 are safe when possible failure areas 1-2, 2-2, 3-2 and 4-2 are not safe in Figure 4b and Table 6. Twelve different cut outs geometry and lancing cutting method were studied to solve tearing problem on around the cut outs, but there was not caught a solution at eleven cut outs geometry as neither the desired failure value nor the wrinkles value as shown in Figure 5. Lancing cutting method clearly solves the tearing problem. However, lancing cutting operation on the drawing die creates small burr problems [13,14] according to stamping production experiences. Due to this problem, lancing cutting method was not considered in this study. Tearing problem was seen on the convex area of cut outs during the eleven attempt shown as Figure 5. Through this determination, decreasing of cut out diameter was considered to ensure less convex area as dimensional and different diameters were tried. Finally, decreasing of cut outs diameter down to 20 mm was close enough to problem solving, this is because resistance to tearing increased when cut out diameter decreased according to simulation results as twelfth attempt. Wrinkle values of possible wrinkle areas are 0,0028 – 0,020 – 0 and 0,049, respectively shown in Figure 6a; in addition to that maximum failure value of possible failure areas are 0,829 – 0,882 – 0,799 – 0,858, respectively shown in Figure 6b and Table 7, when cut outs diameters decreased.

**Table 5.** Relation between yield strength, tensile strength, % elongation, roughness and scrap ratio

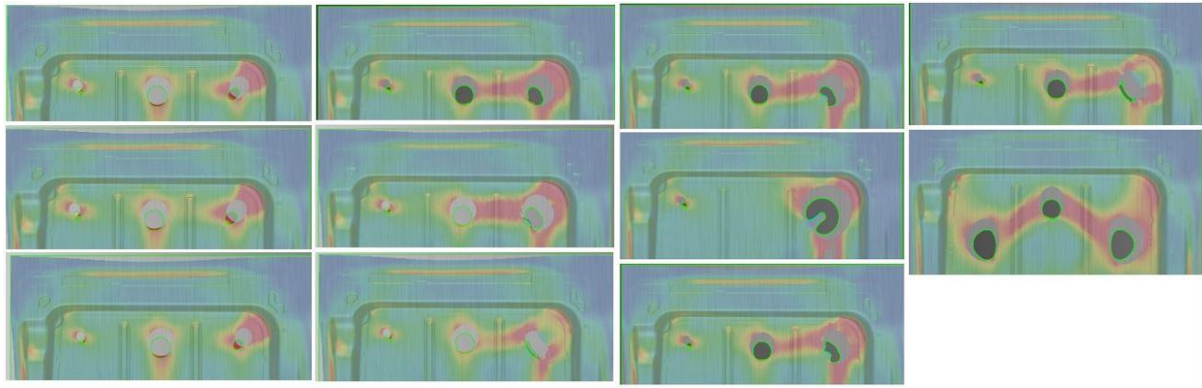
# Sample	Tensile Strength (MPa)	Yield Strength (MPa)	% Elongation	Roughness	%NOK	# OK Part	# NOK Part
1	297	166	46	1,1	0	824	0
2	282	152	46	1,3	1,11	989	11
3	283	154	47	1,1	9,09	869	79
4	290	159	43	1,1	0,72	1245	9
5	277	157	45	1,2	1,98	1012	20
6	290	156	44	1,1	9,89	910	90
7	286	163	43	1,1	8,42	380	32
8	287	161	44	1,3	2,12	1459	31
9	283	160	46	1,1	5,43	829	45
10	275	153	45	1,1	2,68	1009	27
11	289	176	41	1,3	7,65	1464	112
12	290	162	44	1,1	0,39	1016	4
13	287	160	42	1,3	11,6	1948	226
14	289	162	43	1,2	50	196	98
15	292	164	41	1,1	6,15	780	48



**2.1.2. Draw bead force**

Changing of cut outs diameter was close to solve tearing. However, wrinkles level was not solved clearly, despite it approximately decreased 10 times, shown as Fig. 6a and Table 7.

correct force was applied by checking of sheet metal flow. Try-out applications were shown in Figure 9a and Figure 9b. There was not a tearing or wrinkles problem during 10 mass production after increased drawbead force and decreased cut-out diameter.



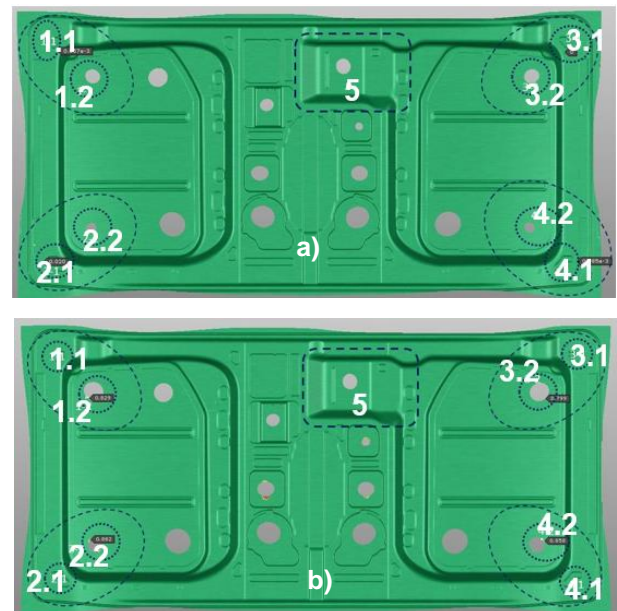
**Figure 5.** Different cut out geometries to prevent tearing

Sheet metal was flowed from drawbead area instead of cut out areas because of that the cut out around was more strength thanks to decreasing of cut out diameter about 20 mm [15]. This situation caused irregular movement of metal from drawbead area. Drawbead force was increased from 90 N. up to 175 N. and result is checked on simulation program to solve wrinkle problem.

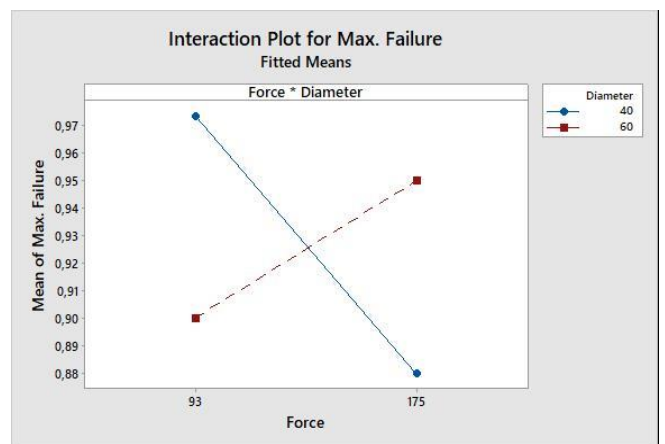
**Table 6.** Possible wrinkle and failure area's Values

Area	Wrinkles Value	Area	Max. Failure Value
1-1	0,028	1-2	0,916
2-1	0,03	2-2	0,956
3-1	0,022	3-2	0,907
4-1	0,029	4-2	0,977

175 N. drawbead force was solved the both wrinkle and tearing problems. This correlation was shown in Figure 7 and show that relations between force and cut out diameter on deep drawing panels. It is the key point of deep drawing part's feasibility and this study. This ratio is called as "MBM Ratio". Potential wrinkle values were zero on area 3-1 and 4-1 after increasing draw bead force was shown in Figure 8. Wrinkles of other areas was at negligible level, because wrinkle level decreased 10 times according to previous situation. Mass production try-out was made to verify solving tearing and wrinkles problem together within this result. Holy strap was applied during try-out process to represent increasing the draw bead force to nearly 175 N. It was verified that correct force was applied by checking of sheet metal flow. Try-out applications were shown in Fig. 9a and Figure 9b. There was not a tearing or wrinkles problem during 10 mass production after increased drawbead force and decreased cut out diameter. It was verified that



**Figure 6.** Wrinkle (a) and failure (b) values after decreased cut out diameter



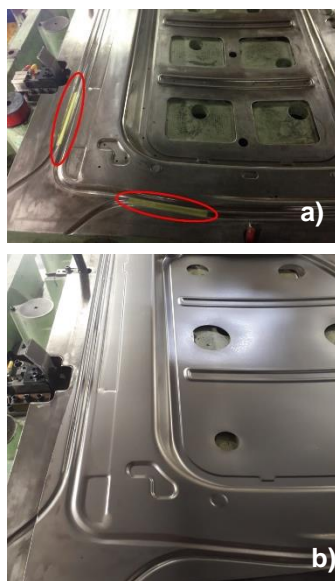
**Figure 7.** Draw bead force and cut out diameter to prevent tearing

**Table 7.** Wrinkle and failure values after decreased cut-out diameter and increased drawbead force

Area	Wrinkles Value	Area	Max. Failure Value
1-1	0,0028	1-2	0,829
2-1	0,002	2-2	0,882
3-1	0	3-2	0,799
4-1	0	4-2	0,858



**Figure 8.** Potential wrinkle values after increased drawbead force

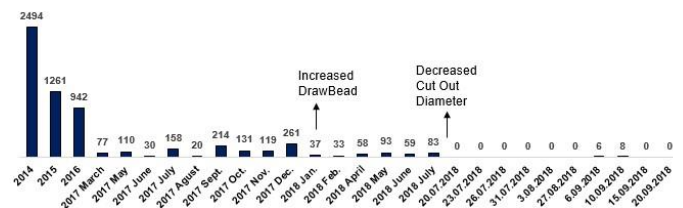


**Figure 9.** Potential wrinkle values after increased drawbead force

### 3. RESULT AND DISCUSSION

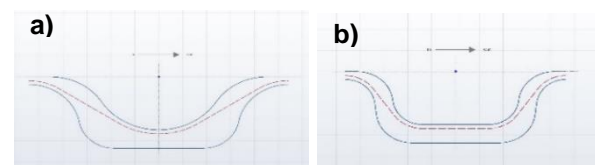
1- A ratio was detected between drawbead force and blank cut out diameter in this study as shown Figure 7 as called “MBM Ratio”. This ratio can be important key point of the deep drawing process with further investigation, but it should be verified with further studies.

2- Stamping line stoppage time was decreased to nearly zero shown as Figure 10. However tearing was occurred around of cut out sometimes as depend on sheet metal mechanical properties. It shows that sheet metal mechanical tolerances can be investigated in next studies.



**Figure 10.** Line stoppage trend

- 3- Lancing method should be tried on drawing operation to solve tearing around of the cut out independently of sheet metal mechanical properties in the further optimization studies.
- 4- Different drawbead geometry should be tried to prevent wrinkles; for example, two & three step progressive rounded drawbead instead of rectangular drawbead systems can be put in use to facilitate try-out and fine tuning at the home line try-out or die construction period. Rounded and rectangular drawbead systems were shown in Figure 11a and Figure 11b, respectively.



**Figure 11.** Line stoppage trend

- 5- As a result of this study, it was understood that maximum failure value definitely should be below 0,9 in order to prevent failure. Additionally, it was certain that maximum failure value should be below 0,8 for exact solution to prevent tearing.



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## DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in their studies do not require ethical committee approval and/or legal-specific permission.

## AUTHORS' CONTRIBUTIONS

**Mehmet Burak MISIRLI:** Performed the experiments, analyse the results and wrote the manuscript.

**Aysun AYDAY:** Supervised the studies and took part in the editing of the article.

## CONFLICT OF INTEREST

There is no conflict of interest in this study.

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