INTERNATIONAL JOURNAL OF AUTOMOTIVE SCIENCE AND TECHNOLOGY

2021, VOL. 5, NO: 4, 386-389 www.ijastech.org e-ISSN: 2587-0963

Incremental Forming of Titanium Grade 2 Sheet by TPIF-RL Method

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Abstract

TPIF-RL method is a new method that gives better wall thickness in incremental forming. In this method, the sheet is not fixed at the edges. Like the deep drawing process, it is compressed with a certain pressure. During the forming process, the sheet flows under the blankholder. Thus, more homogenous wall thickness is obtained.

In this study, Titanium Grade 2 sheet is formed as a cone via TPIF-RL method. Optimum forming parameters were determined by Signal/Noise analysis. In addition, finite element analysis of the process was performed. Using 2 bar clamping pressure, 1000 mm/min feedrate, 0.75 mm increment and 15 mm forming tool diameter optimum result was obtained. With these optimum parameters, 6% thinning occurs on sheet thickness. This new method ensures a homogeneous wall thickness distribution.

Keywords: Incremental sheet forming, Titanium, TPIF-RL method, Thickness distribution, FEM

Research Article

https://doi.org/10.30939/ijastech..999466

Received 22.09.2021
Revised 07.11.2020
Accepted 09.11.2021

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1. Introduction

One of the methods used in prototype production is incremental forming. In this method, the sheet is formed by applying local pressure. Since local pressure is applied, the sheet can be subjected to very large deformation. Therefore, a large thickness change may occur in the sheet. This large change in wall thickness can reduce the industrial usability of the manufactured part [1]. In order to increase the smallest wall thickness of the piece, various studies have been conducted. Some researchers have reduced friction using different lubricants. According to the studies, the reduction of friction positively affected wall thickness [2–4]. Some researchers have reduced the negative effect of friction by coating the forming tool with different materials [5].

When the literature is examined, it is seen that some researchers use heat [6–8]. Some of these researchers heat the work clamping apparatus. Some researchers heat the forming tool. In addition to resistance, a laser can also be used for heating. Less stress occurs during the forming process by the effect of heat. Stress reduction also has a positive effect on sheet thickness [9].

In addition, Seçgin and Özsert aimed to improve the wall thickness with the 'rolling blank holder method' (TPIF-RL method). In this new method, the sheet is not fixed at the edges. The flow of the sheet is allowed. As in the deep drawing process, the sheet flows onto the model. Thus, a more uniform wall thickness distribution is obtained [10]. In this study, Titanium Grade 2 (TiGr2) sheet was formed by using TPIF-RL method. Signal to Noise (S/N) analysis was performed to determine the optimum level of the experimental parameters. In addition, finite element analysis of the method was also performed.

2. Material and Method

In this study, the TiGr2 sheet is formed. This sheet is biomedically compatible. The initial thickness of the sheet is 0.54 mm. From this sheet, axial symmetric cone parts with 40° angle from the horizontal axis are produced. The height of the formed part is 40 mm. Four different factors were examined as pressure, feedrate, increment and forming tool diameter [11–14]. A total of 18 experiments were performed by the TPIF-RL method.

In the rolling blank holder method, the sheet is not fixed by bolts from the edges. With four pneumatic clamps, the clamping force is applied to the edges of the sheet. A ball bearing is located at the end of each pneumatic clamp. Thus, the flow of the sheet is facilitated. When 2 bar pressure is applied to the pneumatic clamp, a clamping force of 187.28 N is generated. When 9 bar pressure is applied, a clamping force of 1039.02 N is generated. During the forming process, depending on the effect of this clamping force, the sheet may flow slightly to the model (Fig. 1). As a result, better wall thickness is obtained.

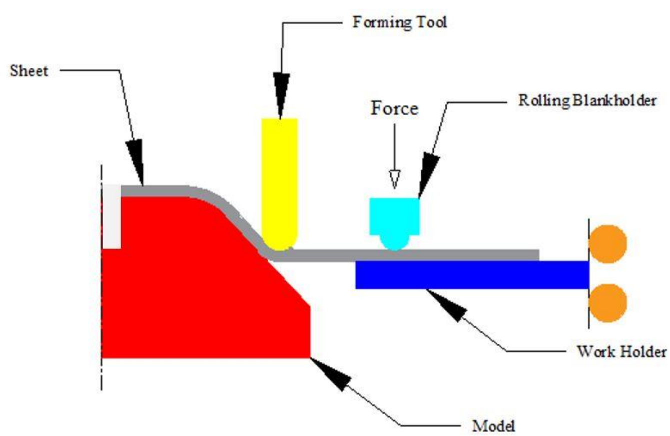

Fig. 1. Rolling blank holder method (TPIF-RL method) [10].

Finite element analysis (FEA) was performed with Abaqus FEM software. Forming tool diameter and model were defined as a rigid body. The sheet was defined as deformable [15–17]. The forming tool movement was defined with three different amplitudes. The analysis was divided into three main steps. In the first step, boundary conditions were defined. In the second step, the sheet was formed. In the last step, the forming tool left the sheet.

The sheet was meshed using quadrilateral shell elements with reduced integration (S4R). The formed area of the sheet meshed with 2 mm elements. Other regions meshed with larger elements. The calculation time was reduced by using different mesh sizes [18–20].

3. Experimental Results

The parts obtained from the experiments were marked at five-millimeter intervals starting from the part center. Wall thicknesses were measured from these marked points. The wall thicknesses on the right side of Table 1 and the experimental set on the left side were given. In experiment 6, a better wall thickness was obtained than the other experiments (minimum thickness of 0.45 mm). In experiment 6, the wall thickness was reducing %13. The smallest wall thickness is 0.42 mm. The maximum thinning amount is 0.12 mm (thickness reduced 22%). According to the table, the wall thicknesses are homogeneously distributed.

Table 1. Experimental set and sheet thickness distribution.

Exp. No	Pressure (bar)	Feedrate (mm/min)	Increment (mm)	Tool Diameter (mm)	Distance from Part Center (mm)													
					5	10	15	20	25	30	35	40	45	50	55	60	65	70
1	2	500	0.25	5	0.54	0.54	0.54	0.53	0.47	0.47	0.47	0.47	0.45	0.45	0.43	0.51	0.54	0.54
2	2	500	0.5	10	0.54	0.54	0.54	0.54	0.44	0.45	0.44	0.45	0.43	0.45	0.46	0.46	0.54	0.54
3	2	500	0.75	15	0.54	0.54	0.54	0.53	0.47	0.47	0.46	0.44	0.45	0.46	0.46	0.48	0.54	0.54
4	2	1000	0.25	5	0.54	0.54	0.54	0.53	0.43	0.44	0.44	0.44	0.43	0.44	0.45	0.51	0.54	0.54
5	2	1000	0.5	10	0.54	0.54	0.54	0.53	0.43	0.44	0.44	0.44	0.45	0.44	0.42	0.46	0.54	0.54
6	2	1000	0.75	15	0.54	0.54	0.54	0.53	0.46	0.46	0.46	0.46	0.46	0.45	0.45	0.5	0.54	0.54
7	2	1500	0.25	10	0.54	0.54	0.54	0.53	0.45	0.45	0.43	0.44	0.44	0.46	0.45	0.52	0.54	0.54
8	2	1500	0.5	15	0.54	0.54	0.54	0.53	0.45	0.45	0.44	0.44	0.44	0.45	0.44	0.45	0.54	0.54
9	2	1500	0.75	5	0.54	0.54	0.54	0.52	0.43	0.42	0.42	0.44	0.45	0.45	0.44	0.54	0.54	0.54
10	9	500	0.25	15	0.54	0.54	0.54	0.53	0.43	0.42	0.43	0.43	0.42	0.42	0.44	0.52	0.54	0.54
11	9	500	0.5	5	0.54	0.54	0.54	0.51	0.43	0.43	0.44	0.44	0.44	0.45	0.46	0.53	0.54	0.54
12	9	500	0.75	10	0.54	0.54	0.54	0.53	0.44	0.44	0.44	0.44	0.44	0.43	0.43	0.44	0.54	0.54
13	9	1000	0.25	10	0.54	0.54	0.54	0.53	0.43	0.44	0.44	0.43	0.43	0.43	0.43	0.51	0.54	0.54
14	9	1000	0.5	15	0.54	0.54	0.54	0.53	0.46	0.43	0.44	0.44	0.44	0.43	0.44	0.52	0.54	0.54
15	9	1000	0.75	5	0.54	0.54	0.54	0.52	0.44	0.44	0.43	0.43	0.44	0.44	0.44	0.5	0.54	0.54
16	9	1500	0.25	15	0.54	0.54	0.54	0.51	0.43	0.42	0.43	0.43	0.43	0.43	0.44	0.51	0.54	0.54
17	9	1500	0.5	5	0.54	0.54	0.54	0.51	0.45	0.45	0.44	0.43	0.44	0.44	0.44	0.54	0.54	0.54
18	9	1500	0.75	10	0.54	0.54	0.54	0.52	0.45	0.44	0.44	0.44	0.44	0.43	0.43	0.5	0.54	0.54

The part obtained from experiment 4 is given in Fig. 2. MoS2 lubricator was used in all experiments to reduce friction [21,22].

Fig. 2. The part obtained from experiment 4.

The thickness distribution obtained from the finite element analysis of experiment 6 is given in Fig. 3.A. As can be seen from the figure, as well as the forming zone, thinning of the wall thickness occurred in the areas where the squeezing pressure was applied. This can also be seen in the test piece. The wall thickness distribution obtained from the finite element analysis of experiment 16 is given in Fig. 3.B.

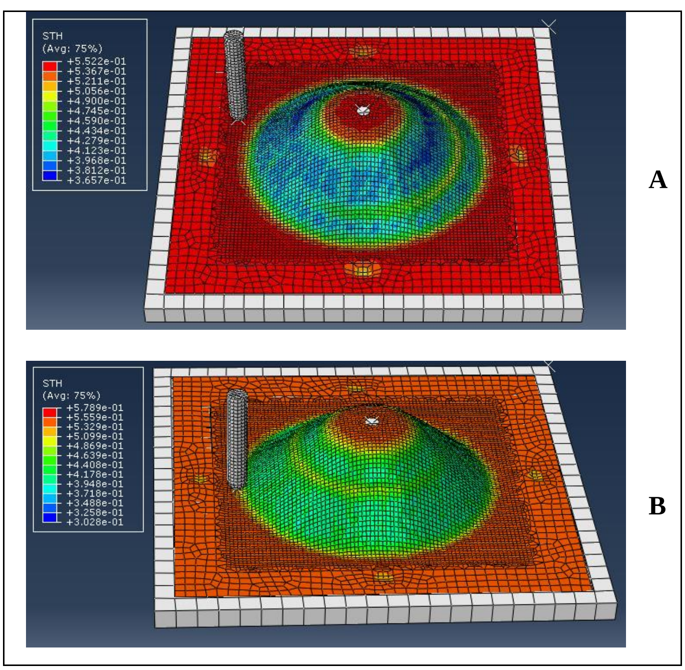

Fig. 3. Sheet thickness analysis. A) Experiment 6. B) Experiment 16.

Fig. 4.A. and

Fig. 4.B. show the wall thickness distribution of the finite element analysis and part obtained from experiment 8 and experiment 12 respectively. In both figures, the experimental results and the FEA results are similar (difference approximately 0.04 mm). According to the experimental results, the sheet was thinned to a maximum of 0.09 mm and 0.1 mm in

Fig. 4.A and

Fig. 4.B respectively.

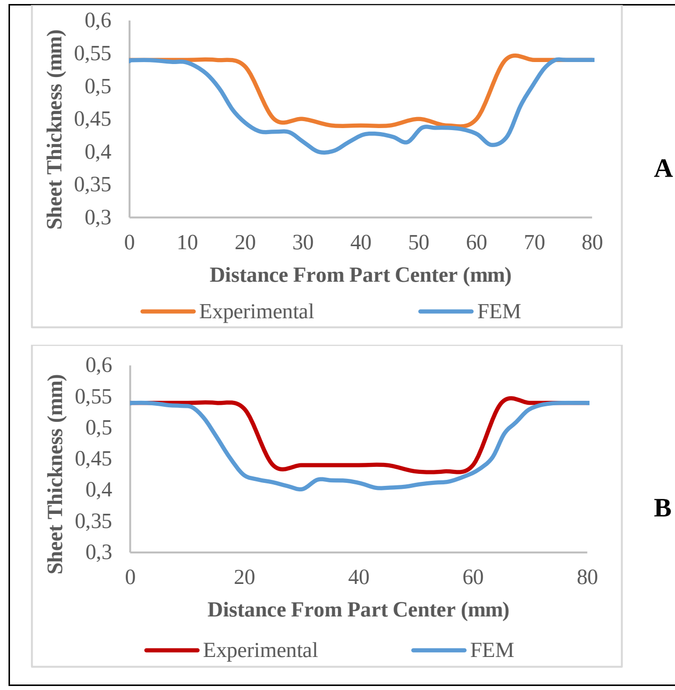

Fig. 4. Thickness comparisons. A) 8th experiment. B) 12th experiment.

The main effect of the S/N ratios obtained by S/N analysis is given in Fig. 5. Optimum levels of parameters according to S/N analysis: 2 bar for pressure, 1000 mm/min for feedrate, 0.75 mm for increment, 15 mm for forming tool diameter. When Table 2 is examined, it is seen that the parameters of Experiment 6 are the same as the optimum values. As can be understood from this result, with the small clamping pressure, the sheet metal flows on the model. This results in less thinning of the sheet.

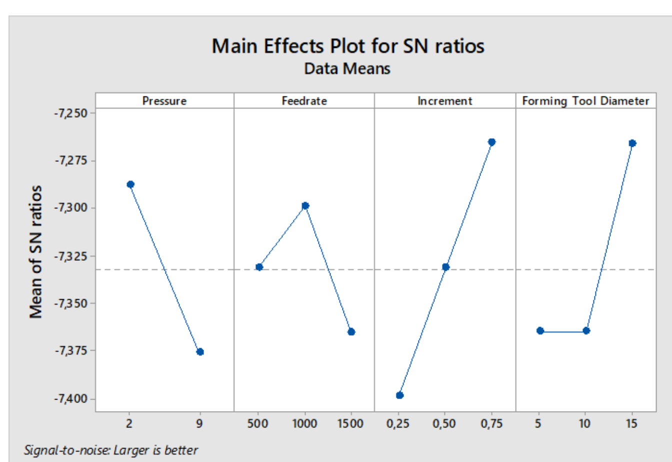

Fig. 5. S/N analysis graphic.

4. Conclusions

A more homogenous wall thickness distribution can be achieved with the 'rolling blank holder method' (TPIF-RL method), which is the result of the development of the traditional incremental forming method. In this study, TiGr2 sheet is formed in axial symmetrical cone form at 40° angle with the horizontal axis. The part height is 40 mm. Optimum levels of parameters according to S/N analysis: 2 bar for pressure, 1000 mm/min for feedrate, 0.75 mm for increment, 15 mm for forming tool diameter. When optimum values are used, a maximum of 6% thinning in wall thickness is achieved. Within the scope of the study, the FEA model of TPIF-RL method was developed. The experimental results and the FEA results are similar (difference approximately 0.04 mm).

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Ö. Seçgin: Conceptualization, Experiments, Measurements, Finite element analysis, Writing, Validation, Data curation,
E. Nart: Finite element analysis, Writing, Validation,
İ. Özsert: Writing-original draft, Finite element analysis, Formal analysis

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