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Research Article

Optimal Experiment Selection in Hydroforming Process of Bimetallic Sheets Using CRITIC, MEREC and TOPSIS Techniques

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ABSTRACT

The present research work is related to the optimal experiment selection of the bimetallic sheet hydroforming process using multi-attribute decision making (MADM) techniques. The numerical simulation of the operation has been done by applying the ABAQUS software. The studied geometrical variables include the punch tip radius (R_p), the die entrance radius (R_d) and the clearance between the punch and matrix (C_L), and the target parameters are the maximum thickness reduction and thickness variation of the final product. In order to calculate the weight of the objective function in sheet hydroforming process, criteria importance through inter-criteria correlation (CRITIC) and method based on the removal effects of criteria (MEREC) techniques were employed. In the following research, a technique for order preference by similarity to ideal solution (TOPSIS) has been used to evaluate the numerical test and assess the best case. The results demonstrated that the weighting coefficients of the two objective functions, namely thickness reduction and thickness variation obtained from CRITIC and MEREC methods, was almost the same. Their values were calculated at approximately 0.6 and 0.4, respectively. Based on the optimization outcomes, the optimal values of R_d, R_p, and C_L gained were 6 mm, 4 mm, and 2.2 mm, respectively.

1. Introduction

The production methods and their development are always of special importance in different industries. Metal forming related to a group of production methods that turn a shapeless or geometric metal into an industrial piece without changing the mass or composition of the metal. The advantages of using metal forming processes to achieve the desired product can be summarized in several cases: 1. good mechanical properties for the produced parts, 2. high production capability and short processing time, and 3. precise tolerances. One of the main common raw materials used in the industry are sheet metals. Sheet metal forming, as one of the most important branches of metal forming, has a special place

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in various industrial fields. In these processes, a desired plastic deformation is created in a primary raw material using a set of rigid die sets. In sheet forming operations, the thickness and area of the initial sheet remain almost constant, but the shape of the product is very different from the original part. Sheet hydroforming process (SHP) is one of the advanced methods that facilitated the production of parts with complex geometries. In this process, in addition to mechanical force, fluid pressure also assists in forming the product in different ways. In comparison with the traditional deep drawing operation, SHP has many advantages, such as high drawing ratio, the ability to form complex parts in unique steps, high dimensional accuracy, better surface quality and low tool cost [1-4]. Although this process has many advantages and promising applications in comparison with the traditional deep drawing operation, use of liquid as a forming medium has led to the high complexity of this process. If these parameters are not selected properly, defects such as wrinkling or tearing will appear in the workpiece. Therefore, in order to obtain products with the desired quality, a careful study and awareness of the effects of parameters on the formability behavior of the sheet metal is necessary. A 3D schematic of the experimental die assembly is given in Fig. 1. As it is known, by moving the punch towards the matrix, the workpiece is formed. The fluid is transferred to the die cavity by the hydraulic pump that affects the bottom surface of the sheet.

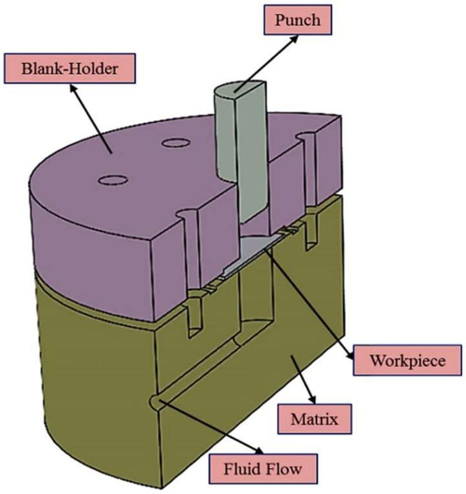


Fig. 1. A 3D schematic of sheet hydroforming die set.

Composite materials have a combination of desirable properties of several materials. In this type of materials, by changing the amount of each of the components or changing how these parts are combined, the desired properties can be created in such a way that each of the components alone does not have that property. This is the unique feature of composite materials, which has led to the use of these materials in various industries. Therefore, with the expansion and practicality of these new materials, the methods of manufacturing and forming of these products also seem very essential [5, 6].

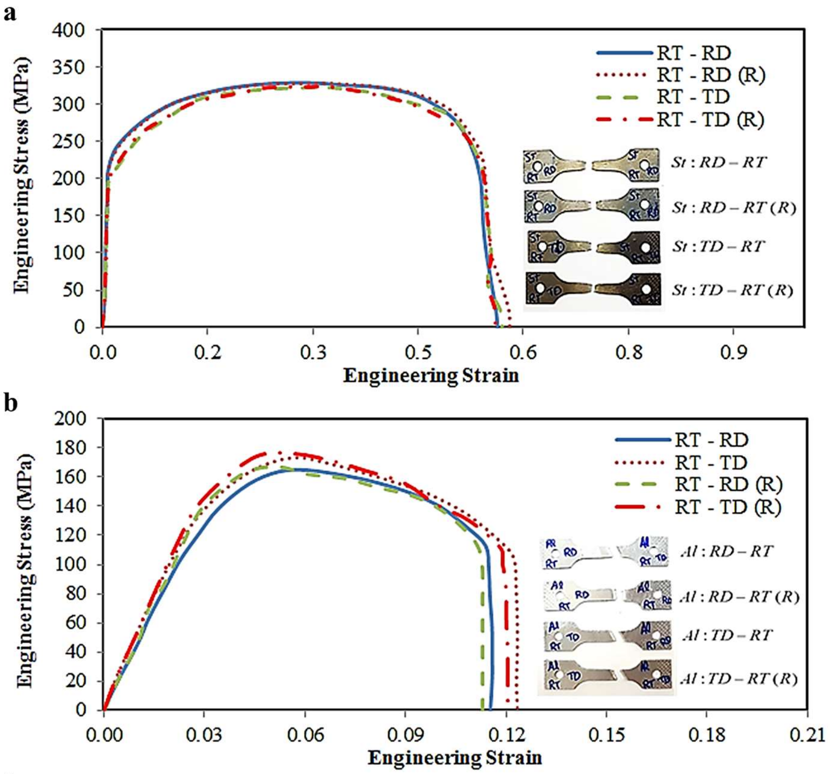
In the field of sheet metals forming via SHP, much research has been done. The effect of stress distribution on spring-back in the hydroforming process was studied by Sun et al. [7]. They obtained the formulation of the spring-back solution from the effect of fluid hydraulic pressure during the bending and stretching of the blank. Based on these relations and with the increase of fluid pressure, the tensile force increases and as a result, the torque and spring-back also decrease. Sadegh-Yazdi et al. [8] optimized the fluid pressure path in the hydro-dynamic deep drawing process using the hybrid method. In their research, optimization was done through ant colony algorithm and fuzzy control. The purpose of their study was to minimize the amount of sheet thinning and wrinkling of produced cups. In another research, Yaghoubi and Fereshteh-Saniee [9] experimentally, numerically, and analytically studied the deformation behavior of Al-St composite products manufactured by the hydro-mechanical deep drawing process. They researched on the effects of maximum fluid pressure, pre-bulge pressure and drawing depth on the quality of final product. The results of their research revealed that by determining the appropriate values of the process parameters, the amount of thickness strain and thickness variation can be improved up to 57% and 68% compared to the traditional deep drawing mode, respectively. Cai et al. [10] analyzed the mechanical analysis of cylindrical aluminum cups in hydro-mechanical deep drawing process at elevated temperatures. Investigating the amount of vertical stress caused by fluid pressure and temperature parameters in this process was the main goals of their research. Turkoz et al. [11] performed numerical optimization of hydro-mechanical deep drawing operation in order to improve the formability of 5754 aluminum alloy sheet. In their research, in order to optimize the amount of fluid pressure and the blank-holder force, the combination of numerical simulation and fuzzy logic control algorithm has been employed. In another research, Hu et al. [12] investigated the deformation behavior of AZ31B Mg-alloy sheet in pulsating the hydroforming process. The outcomes of their research demonstrated an improvement in the formability and delay in the fracture of specimens in comparison with the traditional hydroforming technique. In another study, a comprehensive metallurgical study was conducted on the light alloys produced cups using the hydro-mechanical deep drawing process by Yagoubi and Fereshteh-Saniee [13, 14]. The outcomes of their research revealed that the precipitation hardening overwhelmed the effect of the preferred orientation of the grains in manufactured Al-2024 cups produced by hydro-mechanical deep drawing process. Zhu et al. [15] numerically and experimentally investigated the hot hydroforming process of magnesium sheets. In their research, a new warm forming method was proposed and the influences of process parameters consisting of temperature, friction coefficient and blank-holder force on quality of the products have been studied. Yaghoubi and Fereshteh-Saniee [16] studied the influences of these process parameters on uniformity of laminated composite cups manufactured by hydro-mechanical deep drawing process. They found that the thickness strain and thickness dispersion respectively improved about 27% and 13% by Al/St layer sequence compared to St/Al arrangement. Raja et al. [17] studied on the hydroforming of thin metallic sheets, experimentally and numerically. Their research showed that an appropriate value of formability was observed at around 120 bar pressure. Ozturk et al. [18] investigated the application of bee's optimization algorithm to pulsating hydroforming process. They found that the thickness variation and bulge height improved about 9% and 13%, respectively with the optimizing process.

One of the important topics in the field of discrete optimization is decision-making, which is of particular importance in manufacturing processes. Technique for order preference by similarity to ideal solution (TOPSIS) is a multi-attribute decision making method for evaluating and prioritizing options based on criteria according to their distance from positive and negative ideals. This method was proposed by Lai et al. and soon found its place in multi-attribute decision making [19]. Researchers have conducted limited studies on the application of multi-attribute decision making in manufacturing processes. Akbari et al. [20] performed hybrid multi-objective optimization of B4C/A356 composites produced by friction stir processing (FSP) applying TOPSIS and NSGA-II. In another research, Shukla et al. [21] performed a comprehensive study on the application of TOPSIS technique on different machining operations such as milling, drilling, and turning processes. Visagan and Ganesh [22] researched the parametric optimization of two-point incremental forming using GRA and TOPSIS. They performed analysis of variance with a confidence level of 95% to identify the most effective process variables on the output response.

In the present study, FE-simulation of the sheet hydroforming process has been carried out in order to produce bimetallic specimens consisting of Al-1200 and St-13. The process variables include the die entrance radius (R_d), the punch tip radius (R_p), and the clearance between the punch and matrix (C_L). The purpose of this research is to simultaneously investigate the thickness reduction and define a criterion for determining the uniformity of the final product. Three levels have been defined for each variable and the simulation of the process has been done in full factorial mode. Two target optimizations of the hydroforming operation have been performed using multi-attribute decision making (MADM) techniques, including criteria importance through inter-criteria correlation (CRITIC), method based on the removal effects of criteria (MEREC) and technique for order preference by similarity to ideal solution (TOPSIS), which has not been comprehensively researched in manufacturing processes. Using the mentioned optimization techniques, it is possible to introduce an optimal test in order to achieve the soundness product with a minimum amount of thinning and maximum amount of uniformity.

2. Finite Element Simulation Process

The design and analysis of parts and structures with complex geometry and various loadings have led to the extraction of complicated differential equations, which, in most cases, are impossible to solve through analytical methods. For this purpose, it is possible to solve such differential equations governing engineering problems using the discretization of problems with continuous environments, which are called numerical methods. In the present research, the simulation of the sheet hydroforming operation has been carried out using ABAQUS software. The materials applied in the current study include Al-1200 and St-13, the stress-strain diagrams and mechanical properties of which are shown in Fig. 2. The simulation of the forming process via the hydroforming method has been done through the standard/explicit model. Due to the symmetry of the die set and the process, as well as to reduce the solution time, the simulation of the hydroforming operation has been considered symmetrically and the analysis has been done on the cross-section in two dimensions. The die set includes four parts, which matrix, blank-holder and punch are modeled as analytical rigid and the workpiece is modeled as deformable manner. In the die design, the diameter of the punch was considered to be 40 mm. The workpieces used for the forming process had an initial thickness and diameter of 1 mm and 70 mm, respectively. Fig. 3 shows the deformed bimetal specimens obtained from the hydroforming process for both layered sequences. Based on the stress contour, it can be stated that the region that is in contact with the punch tip has the highest amount of thinning, and the



c

Material	Yield Strength (MPa)	Density (Kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio
St	215.7	7800	200.0	0.30
Al	94.3	2700	70.0	0.33

Fig. 2. The engineering stress-strain diagram for (a) St-13, (b) Al-1200, and (c) their mechanical properties.

increase in the drawing depth of cups can lead to product rupture (Fig. 3(a)). According to the comprehensive studies conducted on the effect of layer arrangement on the formability of the laminated cups by Yaghoubi and Fereshteh-Saniee [16], in the current research, statistical analysis on quality of final product have been carried out for the Al/St layer sequence (Fig. 3(b)).

3. Optimal Experiment Selection Approach

In the current research, multi-attribute decision making (MADM) techniques have been used to select the best experiment., MADM techniques are a kind of multi-objective optimization technique with discrete solution space. In the present study, three techniques in the proposed approach were employed: a) criteria importance through inter-criteria correlation (CRITIC) [23-26], b) method based on the removal effects of criteria (MEREC) [27, 28], and c) technique for order preference by similarity to ideal solution (TOPSIS). CRITIC and MEREC techniques have been used to determine the weight of the criteria, which are the objective functions. Then, the TOPSIS technique employs the weights obtained from the previous two techniques to evaluate the experiment. The main input to all three methods is the decision matrix, the rows and columns of which represent experiments and objective function values for different experiments, respectively. The number of numerical simulation test and objective function in current research work is considered at 27 and 2, respectively. After the weights of the criteria are obtained from CRITIC and MEREC methods, the final weight was calculated to the average of the gained weights. The final weights and the decision matrix are provided as input to the TOPSIS method. The steps and details of the proposed approach for the MEREC-CRITIC and the TOPSIS are shown in Figs. 4 and 5, respectively. The limitation of interest in MADM is the uncertainty in the inputs. Uncertainty is widely employed in decision-making. This phenomenon is due to the existence of ambiguities in decision-making that are created by respondents or problematic data. In this research, there are two inputs in different stages of the proposed approach, which are the subject of uncertainty limitation discussion: the decision matrix and the weight of criteria (attributes). Fortunately, the data of the decision matrix in this research is crisp. Regarding the weight of the attributes, it should be said that the methods that determine these weights based on the judgment of experts are affected by the uncertainty limitation. In order to overcome this limitation, the CRITIC and MEREC methods have been used to determine the weight of the attributes, and these methods obtain the weights using the decision matrix, not based on the judgment of experts.

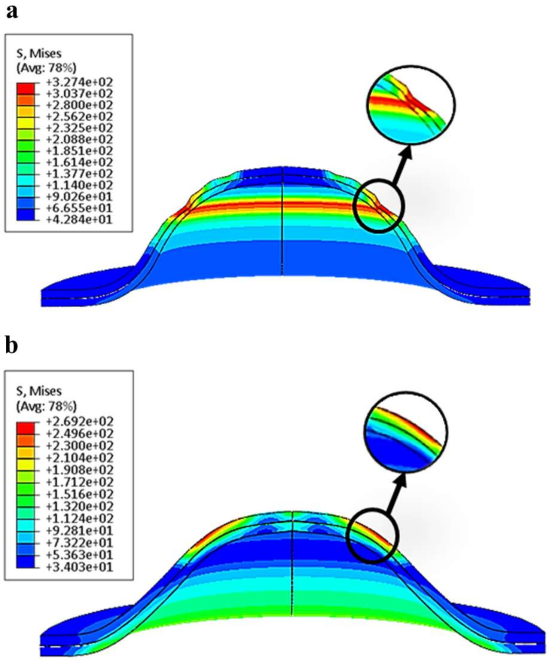


Fig. 3. The contour of von-Mises stress for bimetallic samples obtained from SHP with (a) St/Al and (b) Al/St layers arrangement.

4. Results and Discussion

In the current section, the FE-simulation results have been presented, firstly. After that, the validation of the outcomes has been done through comparison with previous experimental research. In the following, the discrete optimization results used in order to achieve the best numerical test No. obtained from MADM techniques have been reported.

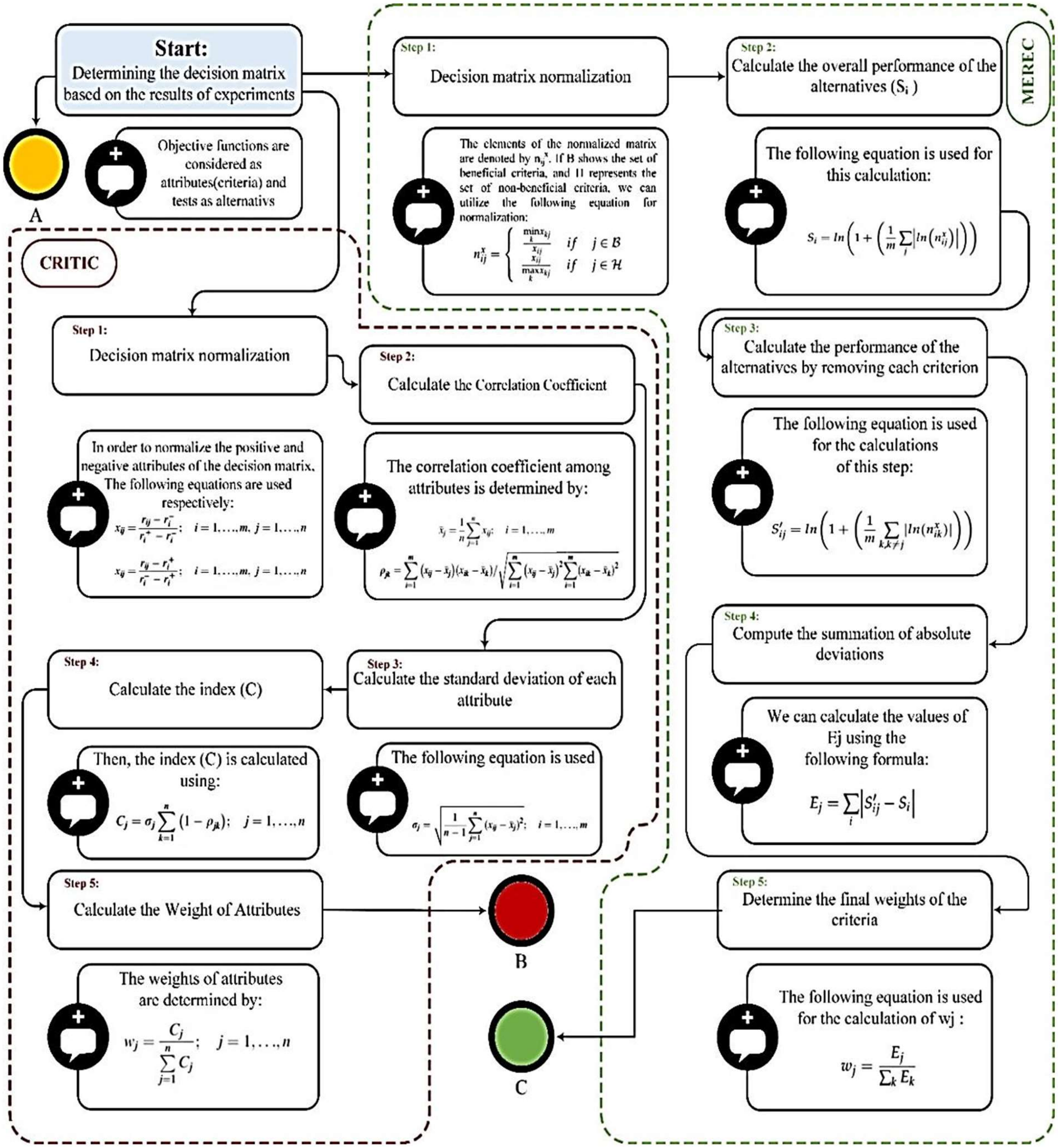


Fig. 4. Selection approach flowchart for CRITIC and MEREC methods.

4.1. FE-simulation results

As mentioned in section 1, one of the main factors for checking the quality of products is thickness reduction, which is calculated using Eq. (1) [29]:

$$R_{th} = \frac{t_0 - t_f}{t_0} \times 100 \qquad (1)$$

where t_0 and t_f represent the initial and the minimum thicknesses of the specimen at the end of the process, respectively. By decreasing in thickness reduction, the quality of the laminated products increases.

In order to determine the uniformity of the final product, multiple criteria can be introduced. In this research, in order to determine the uniformity of

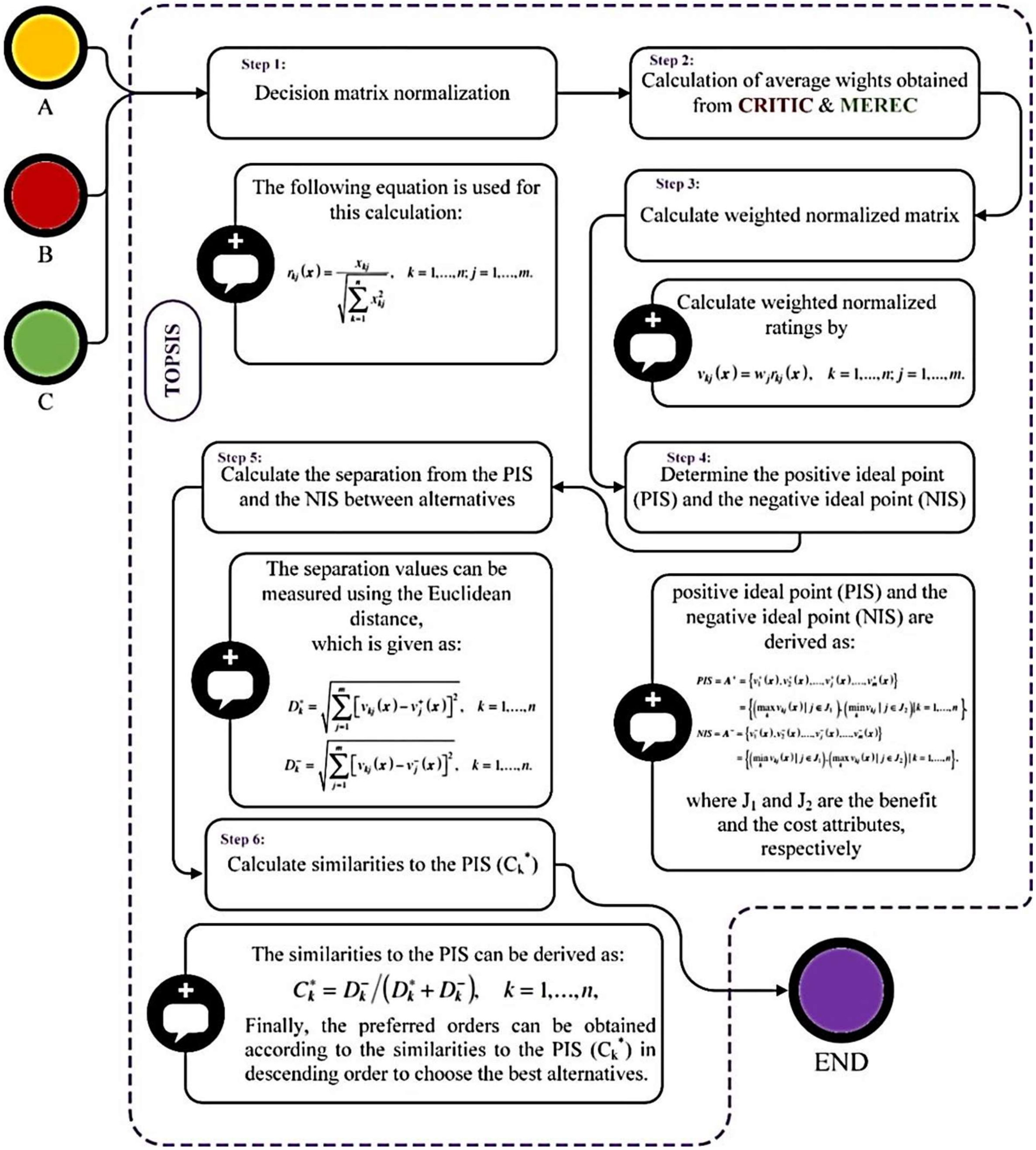


Fig. 5. Selection approach flowchart for TOPSIS method.

composite specimens, the parameter of thickness variation has been used. Here, the uniformity means that the thickness of the produced cup has minimum variations with respect to the average thickness of the final laminated cups. By reducing the amount of this parameter, the uniformity of the specimens increases. Regarding this criterion, Eq. (2) is applied to determine the uniformity of the deformed cup [30]:

$$V_{th} = \sum_{i=1}^{p} \left| \frac{t_{ave} - t_i}{t_{ave}} \right| \qquad (2)$$

In the above equation, p represents the number of points marked on the diagram of thickness distribution in terms of the distance from the center of the blank. In addition, t_i is the workpiece thickness at the ith point and t_{ave} is the average thickness of the deformed laminated product.

The outcomes of the numerical results obtained from FE-simulation via the ABAQUS software are presented in Table 1. It should be noted that in this data set, the maximum fluid pressure is considered to be 150 bar. In this study, with the aim of optimizing the two objectives of thickness reduction and thickness variation, three variables with three levels have been analyzed in full factorial state. The research variables are in millimeters and the target parameters are dimensionless quantities.

Table 1. Results of numerical simulation of the hydroforming process

Test No	R_d	R_p	C_L	R_{th}	V_{th}
1	4	4	2.2	22.42	1.907
2	4	4	2.3	21.92	1.958
3	4	4	2.4	21.05	1.991
4	4	6	2.2	20.94	1.949
5	4	6	2.3	19.56	1.999
6	4	6	2.4	18.31	2.025
7	4	8	2.2	19.75	1.983
8	4	8	2.3	17.87	2.049
9	4	8	2.4	16.32	2.084
10	6	4	2.2	20.88	1.848
11	6	4	2.3	20.05	1.957
12	6	4	2.4	19.78	2.025
13	6	6	2.2	18.75	1.915
14	6	6	2.3	17.97	2.041
15	6	6	2.4	17.12	2.117
16	6	8	2.2	18.25	1.991
17	6	8	2.3	17.11	2.125
18	6	8	2.4	16.31	2.226
19	8	4	2.2	19.97	1.891
20	8	4	2.3	18.84	1.998
21	8	4	2.4	17.51	2.117
22	8	6	2.2	18.54	1.999
23	8	6	2.3	17.23	2.109
24	8	6	2.4	16.21	2.201
25	8	8	2.2	17.89	2.084
26	8	8	2.3	16.97	2.209
27	8	8	2.4	16.22	2.302

In this section, the aim is to validate the numerical results obtained from the FE-simulation of sheet hydroforming process. For this purpose, the amount of R_{th} and V_{th} was calculated in presence of different values for the maximum fluid pressure and under equal experimental conditions. The results of the validation are given in Table 2. According to observations made, it can be stated that the simulation results have acceptable accuracy and are reliable.

Table 2. Validation of obtained numerical results

Fluid pressure (bar)	0		50		150		250	
	R_{th} (%)	V_{th}	R_{th} (%)	V_{th}	R_{th} (%)	V_{th}	R_{th} (%)	V_{th}
Exp-results [16]	26.7	3.23	17.1	3.05	15.1	2.35	20.5	2.85
FE-results	28.4	3.51	17.9	3.31	13.9	2.24	22.9	3.09

4.2. Optimization results

The summary of the CRITIC results is given in Table 3. The first column shows the number of experiments, and the decision matrix is in the second and third columns. The normalized decision matrix using the method mentioned in Fig. 4 is in the fourth and fifth columns. At the bottom of the table, the values of the correlation coefficient, standard deviation, index C_j and weight of the criteria are computed. According to the CRITIC results, the thickness reduction and the thickness variation weights are calculated to 0.6045 and 0.3955, respectively.

Table 4 shows the outcomes obtained from the MEREC method. Based on the decision matrix shown in this table and according to the MEREC method illustrated in Fig. 4, the first and second columns represent the normalized decision matrix. At the bottom of Table 4, the values of criteria weight are computed. The thickness reduction and thickness variation weights are calculated at 0.6078 and 0.3922, respectively. Based on the MEREC results, the weights obtained from the CRITIC and MEREC methods are very close to each other. The concise results gained from the TOPSIS method are presented in Table 5. In the first and second columns, according to the method illustrated in Fig. 5, the normalized decision matrix is shown. At the bottom of the table, the average weights obtained from the previous two methods have been calculated and used as input to the TOPSIS method. After the implementation

Table 3. Results obtained from CRITIC technique

Decision Matrix			**Normalized Decision Matrix**	
Alternatives	**Attributes (Criteria)**		**R_{th} (%)**	**V_{th}**
	R_{th} (%)	**V_{th}**		
Test 1	22.42	1.907	0.0000	0.8700
Test 2	21.92	1.958	0.0805	0.7577
Test 3	21.05	1.991	0.2206	0.6850
Test 4	20.94	1.949	0.2383	0.7775
Test 5	19.56	1.999	0.4605	0.6674
Test 6	18.31	2.025	0.6618	0.6101
Test 7	19.75	1.983	0.4300	0.7026
Test 8	17.87	2.049	0.7327	0.5573
Test 9	16.32	2.084	0.9823	0.4802
Test 10	20.88	1.848	0.2480	1.0000
Test 11	20.05	1.957	0.3816	0.7599
Test 12	19.78	2.025	0.4251	0.6101
Test 13	18.75	1.915	0.5910	0.8524
Test 14	17.97	2.041	0.7166	0.5749
Test 15	17.12	2.117	0.8535	0.4075
Test 16	18.25	1.991	0.6715	0.6850
Test 17	17.11	2.125	0.8551	0.3899
Test 18	16.31	2.226	0.9839	0.1674
Test 19	19.97	1.891	0.3945	0.9053
Test 20	18.84	1.998	0.5765	0.6696
Test 21	17.51	2.117	0.7907	0.4075
Test 22	18.54	1.999	0.6248	0.6674
Test 23	17.23	2.109	0.8357	0.4251
Test 24	16.21	2.201	1.0000	0.2225
Test 25	17.89	2.084	0.7295	0.4802
Test 26	16.97	2.209	0.8776	0.2048
Test 27	16.22	2.302	0.9984	0.0000
max r_{ij}	22.42	2.302	Average	
min r_{ij}	16.21	1.848	0.6060	0.5755
	$\rho_{jk} =$		-0.3627	
	$\sigma_j =$		3.3344	2.1819
	$C_j =$		4.5436	2.9732
	$W_j =$		**0.6045**	**0.3955**

of the TOPSIS technique, the 10th numerical test (shown in Table 1) is selected as the best alternative.

The die entrance radius is one of the most remarkable geometrical parameters. Decreasing this parameter increases the possibility of tearing the final product and increasing it to a large degree causes wrinkling on the edge of the workpiece and as a result reduces the uniformity of the laminated cup. Increasing the die entrance radius causes large bending and tensile strains in the flange area of the matrix. This change had a direct effect on reducing the uniformity and quality of the final product. Hence, it is logical that the influence of the radius of the die entrance on the uniformity of the final product is greater than its effect on the tearing of the produced cup. Another effective geometrical parameter in SHP is its excessive reduction (increasing the

Table 4. Results obtained from MEREC technique

Normalized Decision Matrix		S_i	S'_{i1}	S'_{i2}	$\lvert S'_{i1} - S_i \rvert$	$\lvert S'_{i2} - S_i \rvert$
R_{th}	V_{th}					
1.0000	0.8284	0.0900	0.0900	0.0000	0.0000	0.0900
0.9777	0.8506	0.0882	0.0778	0.0112	0.0104	0.0770
0.9389	0.8649	0.0990	0.0701	0.0310	0.0290	0.0680
0.9340	0.8467	0.1110	0.0799	0.0336	0.0310	0.0774
0.8724	0.8684	0.1300	0.0682	0.0660	0.0618	0.0640
0.8167	0.8797	0.1530	0.0621	0.0964	0.0909	0.0566
0.8809	0.8614	0.1293	0.0719	0.0615	0.0573	0.0678
0.7971	0.8901	0.1584	0.0566	0.1074	0.1018	0.0510
0.7279	0.9053	0.1894	0.0485	0.1474	0.1409	0.0420
0.9313	0.8028	0.1358	0.1042	0.0350	0.0316	0.1008
0.8943	0.8501	0.1284	0.0781	0.0544	0.0504	0.0741
0.8822	0.8797	0.1193	0.0621	0.0608	0.0572	0.0586
0.8363	0.8319	0.1667	0.0880	0.0856	0.0787	0.0811
0.8015	0.8866	0.1577	0.0584	0.1049	0.0993	0.0528
0.7636	0.9196	0.1627	0.0410	0.1265	0.1217	0.0362
0.8140	0.8649	0.1617	0.0701	0.0979	0.0916	0.0637
0.7632	0.9231	0.1614	0.0392	0.1268	0.1222	0.0346
0.7275	0.9670	0.1620	0.0166	0.1476	0.1454	0.0144
0.8907	0.8215	0.1451	0.0938	0.0562	0.0513	0.0889
0.8403	0.8679	0.1465	0.0684	0.0834	0.0781	0.0631
0.7810	0.9196	0.1531	0.0410	0.1165	0.1121	0.0366
0.8269	0.8684	0.1532	0.0682	0.0908	0.0850	0.0625
0.7685	0.9162	0.1616	0.0429	0.1237	0.1188	0.0380
0.7230	0.9561	0.1694	0.0222	0.1503	0.1472	0.0191
0.7979	0.9053	0.1507	0.0485	0.1069	0.1021	0.0437
0.7569	0.9596	0.1483	0.0204	0.1304	0.1279	0.0179
0.7235	1.0000	0.1500	0.0000	0.1500	0.1500	0.0000
max x_{ij}	22.42	2.302	E_j		2.2936	1.4798
min x_{ij}	16.21	1.848	W_j		0.6078	0.3922
Aspect	-	-				

sharpness of the punch tip) which increases the thinning leads to the tearing of the workpiece. Considering that the edge of the punch has a direct relationship with the corners of the deformed sheet, it is logical that this parameter has a greater effect on sheet tearing than the uniformity of the product. The third geometrical parameter investigated in the current research work is the clearance between the punch and the matrix. By increasing the amount of this parameter, the available space between the punch and the die increases and, as a result, the sheet metal forming force decreases. The main problem of increasing the value of clearance is increasing the thickness variation (reducing the quality of the final product) due to the presence of suitable space. Since the amount of forming force is low in sheet metal forming processes and the uniformity of the product is important, therefore, the clearance parameter should be minimized as much as possible. Based on the mentioned cases, it can be stated that the optimal test obtained from the CRITIC, MEREC, and TOPSIS techniques seem reasonable.

Table 5. Results obtained from TOPSIS method

Normalized Decision Matrix		Weighted Normalized Decision Matrix		D_k^*	D_k^-	C_k^*	Rank
0.0004	0.0066	0.00023	0.0026	0.00000000027	0.0000000141	0.981597	4
0.0004	0.0067	0.00022	0.0027	0.00000000078	0.0000000101	0.928599	7
0.0004	0.0069	0.00022	0.0027	0.00000000133	0.0000000080	0.856955	10
0.0004	0.0067	0.00021	0.0026	0.00000000062	0.0000000108	0.946003	5
0.0003	0.0069	0.00020	0.0027	0.00000000145	0.0000000075	0.838134	13
0.0003	0.0070	0.00019	0.0027	0.00000000208	0.0000000061	0.746541	14
0.0003	0.0068	0.00020	0.0027	0.00000000113	0.0000000085	0.883141	8
0.0003	0.0071	0.00018	0.0028	0.00000000281	0.0000000050	0.638633	17
0.0003	0.0072	0.00017	0.0028	0.00000000411	0.0000000036	0.465525	18
0.0004	0.0064	0.00021	0.0025	0.00000000004	0.0000000198	0.997841	1
0.0003	0.0067	0.00021	0.0027	0.00000000070	0.0000000103	0.936232	6
0.0003	0.0070	0.00020	0.0027	0.00000000212	0.0000000061	0.741467	15
0.0003	0.0066	0.00019	0.0026	0.00000000022	0.0000000135	0.984027	3
0.0003	0.0070	0.00018	0.0028	0.00000000255	0.0000000053	0.676649	16
0.0003	0.0073	0.00018	0.0029	0.00000000563	0.0000000024	0.300596	21
0.0003	0.0069	0.00019	0.0027	0.00000000125	0.0000000081	0.865655	9
0.0003	0.0073	0.00018	0.0029	0.00000000604	0.0000000022	0.265871	23
0.0003	0.0077	0.00017	0.0030	0.00000001272	0.0000000004	0.030056	26
0.0003	0.0065	0.00020	0.0026	0.00000000011	0.0000000156	0.993218	2
0.0003	0.0069	0.00019	0.0027	0.00000000141	0.0000000076	0.843429	11
0.0003	0.0073	0.00018	0.0029	0.00000000563	0.0000000024	0.298827	22
0.0003	0.0069	0.00019	0.0027	0.00000000143	0.0000000076	0.841106	12
0.0003	0.0073	0.00018	0.0029	0.00000000524	0.0000000027	0.33692	20
0.0003	0.0076	0.00017	0.0030	0.00000001080	0.0000000007	0.058998	24
0.0003	0.0072	0.00018	0.0028	0.00000000412	0.0000000035	0.458909	19
0.0003	0.0076	0.00017	0.0030	0.00000001140	0.0000000005	0.045599	25
0.0003	0.0079	0.00017	0.0031	0.00000001975	0.0000000001	0.004257	27
W_j (CRITIC)		0.604461083		0.395538917	PIS(A^+):	0.00017	0.0025
W_j (MEREC)		0.607835906		0.392164094	NIS(A^-):	0.00023	0.0031
W_j(Average)		**0.6061**		**0.3939**			

5. Conclusion

In the current study, the FE-simulation of the hydroforming process of bimetallic sheets has been done using the ABAQUS software. The materials used to produce bimetallic specimens included Al-1200 and St-13. The aim of the present research was to optimize the two objectives of the sheet hydroforming process using multi attribute decision making (MADM) techniques. Process variables included die entrance radius, punch tip and clearance between the punch and matrix, each of which was defined in three levels. Thickness reduction and thickness variation of the laminated product were considered as objective functions. Criteria importance through inter-criteria correlation (CRITIC) and method based on the removal effects of criteria (MEREC) techniques have been employed to calculate the weight of the objective targets. After that, technique for order preference by similarity to ideal solution (TOPSIS) method uses the weights obtained from the CRITIC and MEREC methods to evaluate the experiment and determine the best case. The outcomes of current study are summarized as below:

- Based on the research observations, it can be stated that the punch tip radius has a greater effect on the thinning products, while the die entrance radius and clearance changes have a greater effect on the uniformity of the laminated cups.

- The weights of the objective functions obtained from the CRITIC and MEREC methods are almost similar, so that the thickness reduction and thickness variation weights were calculated at about 0.6 and 0.4, respectively.
- According to the TOPSIS technique, in which the average weights of the CRITIC and MEREC methods are used, the 10th test was introduced as the best case.

Conflict of Interests

The authors declare no conflict of interest.

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