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Research paper

Investigation of Chained Process Quality for Product Design Using FEM and Experimental Verification

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Abstract

In this research, chained process simulation is to be investigated to solve the major problem of component distortion which is commonly occurred and cannot be neglected in fabrication process. Stamping-welding as coupled process is the main concern to be reassembled into simulation under consideration of property history transferred from previous process. The selected component geometry is rear arm as parts of automotive steering structure made of material SPH440 and STKM13A. The FEM simulation starts with the modeling of real components and executed based on actual hydraulic stamping followed by GMAW process parameters. In both simulation processes, nonlinear isotropic hardening model was used taken from existing software database of equivalent material properties. The experimental investigation is conducted for verification purpose. The conclusion can be drawn throughout the research that the specialized FEM software Simufact Forming and Simufact Welding had outstanding capability to predict final distortion for complex chained processes with complex geometry.

Keywords: *Chained Process; Distortion; Simulation; Stamping; Welding.*

1. Introduction

In manufacturing industries especially in automotive, stamping and welding are the most important process, economical and efficient way to form and permanently join metals. During stamping process, materials deal with springback and residual stress meanwhile welding a weldment experiences complex temperature changes that cause transient thermal stresses and non-uniform distribution of elastic strains that are produced in the weld and the regions near it. Distortion can affect the performance of welded structure and also can affect dimensional accuracy of the weldment and thus, need to be controlled [1, 2].
Manufacturing is defined as a process of fabricating goods and steps through which raw materials are transformed into a finished or final product. The product design and manufacturing disciplines are thoroughly linked because deliberation of how a component is to be manufactured is often a defining standard for a successful design [1]. There are some processes used precedence to quality and quantity, for example, stamping, forging and punching. These methods are the most commonly processes used and the oldest technique in metal processing. On to metal joining process, welding is the one of the most popular process that offers most homogenous joints and permanently. The welding process is done by melting and fusing the parts with or without filler material.
Process simulation in manufacturing industry is becoming a common tool in design and development sections. Simulation model- ling and analysis is the process of creating and analyzing with a computerized mathematical model of a physical system [2]. Some of parts can be manufactured at lower cost and in less time if use process simulations first before the real process conduct [3]. Simulations are a part of Virtual Manufacturing. Popular method that is useful in industry is Finite Element Method (FEM). FEM is a general method to study, analyze and simulate the physical behavior of mechanical part specifically the processes of forming, welding and cutting [4].
Chaining process can be described as placed on process chain analysis of selected metal forming and welding processes. Process chain also being used in another field which is from business processes to factory layout [5]. The description is in journal Arjaan Buijk et al. [6]. Chaining process contains from forming process to welding process which is the data and product from forming process brought to welding process. Therefore, the main problem in the welding process is the value of distortion of the product. Distortion happened during weld, the contraction and expansion of weld metal and base metal during heating and cooling process of welding [7]. Welding distortion is one of the major reasons to the product dimensional inaccuracy and become a problem in production which is involve high tolerance in dimension [8]. Distortion can also cause damage or changes in geometry aesthetic value and strength of product.
Therefore, in this paper, chaining process is to analyze the distortion of the product which is rear arm by undergoes the forming process. The best approach to analyze and handle these complicated processes efficiently is finite element method. In this paper, welding distortion is being compared with chaining process and unchaining process of the product. Many researchers have been conducted to initiate the value of distortion but the distortion cannot be eliminated completely.

2. Modeling and Simulation Procedure

The distortion of rear arm is being analyzed using simulation. The purpose is to compare the distortion of rear arm with chaining process and rear arm with unchaining process and verify to the distortion of rear arm that actually happened in industry. The objective of this study can be achieved by approaching this project methodology, to finalize the results between the two simulation processes.

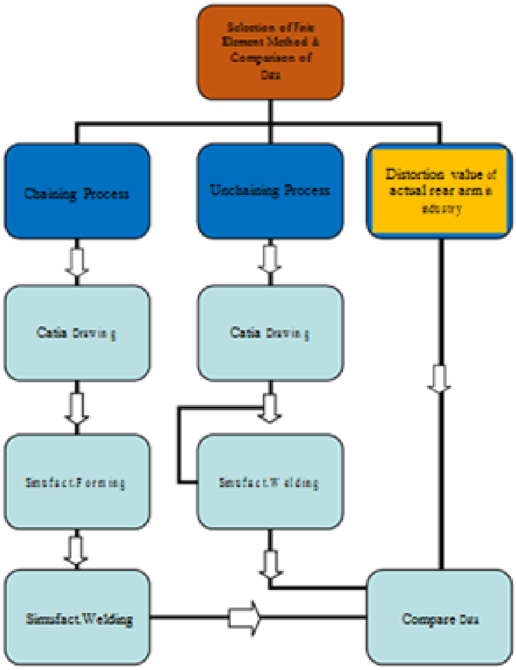

Fig. 1: Data Collection for comparison between chaining and unchaining to actual industrial product

Figure 1 show between chaining and unchaining process and the third row is to verify the simulation results using automated welding process. Catia V5 is used to draw the model of rear arm. A set of a die is used for the forming process and Catia V5 is also used to design a simplified die set. Thus, the parameter of the current model of rear arm is used instead of a new one in the market.

All the parameters of simulation need to be defined before the simulation start. Both process of chaining and unchaining required physical data at the beginning of the simulation. The physical data need to be modified and matched with the parameter from industry. Simufact.Forming 14.0 software is used to modify the physical data, meshed for the pre-processing stage so that the simulation in the solvent stage can be performed. Simufact.Welding 5.0 is used for the welding simulation, the parameter of the welding process is similar to the parameter given by industrial. Not all the parameter is actual with the industry but, the only rough approximation of heat source used in simulation caused the difference between actual and numerical in the simulation. Data of the forming process in Simufact Forming 14.0 was export into Simufact.Welding 5.0 by using .spr file. The results of distortion of two processes are obtained at the end or post-processing stage of simulation.

2.1 Geometrical modeling using CATIA

Rear arm assembly contains body, collar and attachment. In chaining process, the rear arm goes through forming process, and then the data brought into welding process. The drawing of rear arm dies and workpiece is exported into Simufact Forming 14.0 in .stl file. Meanwhile, unchaining process, rear arm drawing in Catia is transferred into MSC Patran for meshing purpose in .igs file. Then, it will export into Simufact Welding 5.0 in .bdf file. In Figure 2 shows the rear arm of CAD drawing (top) and actual rear arm (bottom).

Figure 2: Rear arm of CAD drawing and actual rear arm

2.2. Chained process simulation using Simufact

The parameter for stamping process is obtained from the industry. Preliminary processing of this software requires these parameters to run the simulation. Table 1 tabulates the parameters used in simulation of Simufact.Forming 14.0.

Table 1: Parameters for stamping simulation

Forming process	Sheet forming
Process type	Cold stamping
Ambient temperature	20ºC
Material	SPH440
Press	Hydraulic press
Die friction	Medium
Temperature	Die (20ºC) / Sheet metal (20ºC)
Mesh	5 mm hexahedral
Stroke	50 mm

Preliminary processing for this simulation needed physical parameter to run the simulation. The heat source can be done by considering calculating thermal input along the welding path. Chaining process can be done using this software by transferred data from Simufact.Forming 14.0 in .spr file. Unchaining process, after meshed in MSC Patran software, export .igs file into this software to run the simulation. The parameters that used in the Simufact.Welding 5.0 is stated in Table 2 and the setup of welding simulation is shown in Figure 3.

Table 2: Parameter for welding simulation

Process type	Arc Welding
Number of bearing	2
Number of clamping	4
Clamping deactivation	3s after welding process
Clamping force	4200 N Number of robotic welding
Number of weld path	6

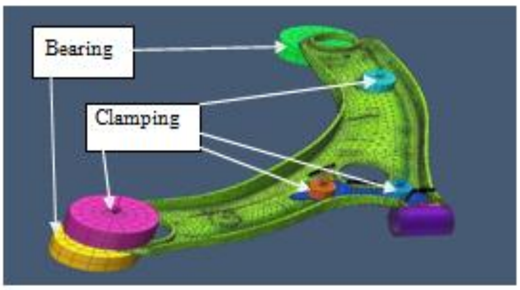

Fig. 3: Setup for welding simulation

Materials selected for this simulation is crucial since each type of material has their own characteristics. Thus, the material selected from software library provided in simufact. The material from software library is the most similar with the actual from industry. There are two types of materials used in this simulation process. One part is for the body and attachment, and the other one is for the collar. Table 3 below represents the material used in this simulation:

Table 3: Material used in simulation

Part	Body attachment	Collar
Material	SPH440	STKM13A
Type of steel	General steel	General steel
Poison's ratio	0.3	0.3
Density	7852.17kg/m^3	7852.17 kg/m^3
Manganese composition	1.1 %	0.9%

2.3 Heat source calibration for welding simulation

Heat source calibration for welding process is important for validity in solving the real life problem [9]. Without proper heat source calibration, a result from welding simulation has lost the valid ability because of different with the experimental. Thus, heat source in Simufact Welding 5.0 ought to be calibrated first to increase suitable distribution heat source on the welding path. A common heat source model for arc welding process is Goldak's double ellipsoid is used in this welding simulation. Therefore, to define a precise numerical description of the heat source is very important towards the genuine assurance of the proper material structure, real strains and residual stresses. Reported the following findings from M. Hashemzadeh et.al [10], semi ellipsoidal and double ellipsoidal models represent well experimental and real conditions in numerous welding procedures, for example, GMAW or laser welding.
The problems of distortion, residual stresses and grain structure of a product is about of a weld joint occur directly from thermal cycle by localized intense heat input of fusion welding. Primary objective for weld process selection and weld plan development is decreasing the heat input to the work piece [11]. In this paper, Goldak's ellipsoidal moving heat source was used. Thus, the most commonly acceptable heat source model was represented by Goldak's model used for the Finite Element Method as demonstrates in Figure 4.

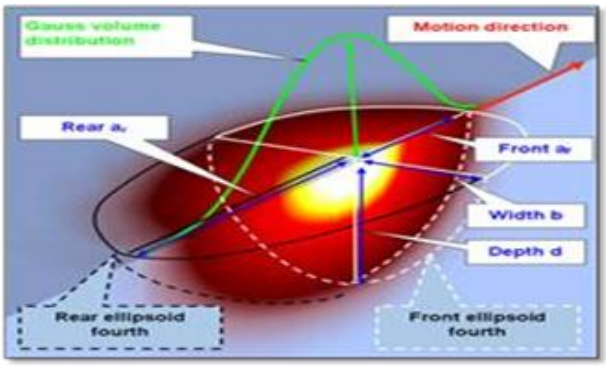

Fig. 4: Goldak's double ellipsoid heat source model

The heat source parameters used for Goldak's double ellipsoid heat source model used in this study is tabulated in Table 4 below. Heat source parameters needed to be calibrated in accordance with the rule of procedure for the simulation process. The calibration associated with process where micrograph analysis was conducted for welding path which is path 1. As reflected in Figure. 5 shows the good agreement of the fillet weld both by experimental and simulation process.

Table 4: Goldak's Double Ellipsoid Heat Source Parameters

Frontal length (a_f)	2.5 mm
Rear length (a_r)	3.5 mm
Width (b)	4.5 mm
Depth (d)	5.0 mm

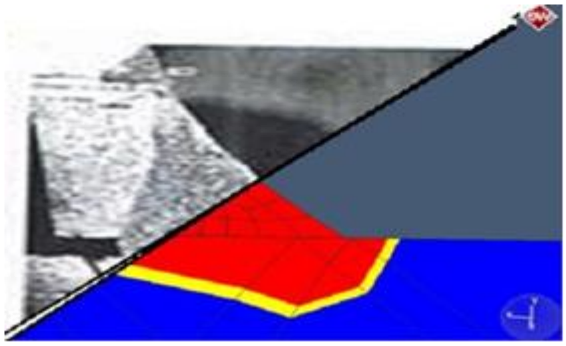

Fig. 5: Calibration procedure

2.4 Simulation procedure

In this simulation, both chaining and unchaining process contain stamping process and welding process. After stamping process has been done through Simufact Forming 14.0, welding process is applied to the rear arm with attachment and collar. In this process, the welding sequence used in this simulation is same with the welding sequence of actual rear arm. Figure 6 shows the position of welding sequence for chaining and unchaining process respectively.

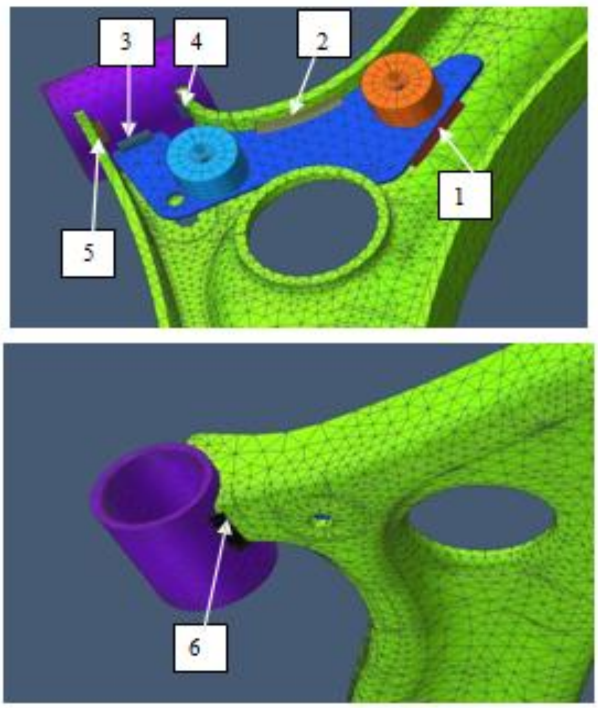

Fig.6: Welding Sequence of chaining and unchaining process simulation

The welding sequence for this process is 123456 sequences. This welding sequence obtains better results from the other sequences in this process. Therefore, three points have been selected to obtain the results of distortion. The tracking points are selected based on most effective point in the direction of smaller value is better in terms of distortion. Figure 7 below demonstrates the selected tracking points in this simulation for both chaining and unchaining simulation.

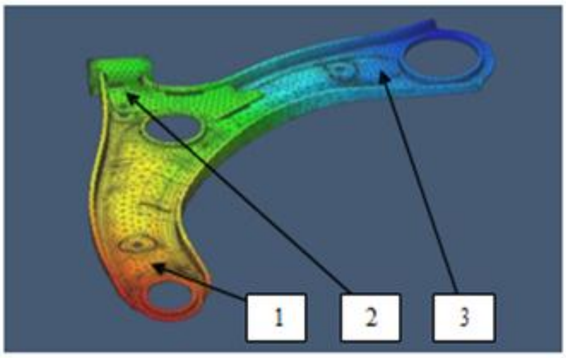

Fig. 7: Selected tracking points of chaining and unchaining process simulation

Each welding path of the welding sequence has a different parameter. Hence, each welding path has different in length, velocity, current, voltage and welding angle. Therefore, the value of distortion is different for each of the welding sequences. Table 5 represents the position of welding sequence and welding sequence parameter, respectively.

3. Result and Analysis

Post processing of the simulation process gives the results in terms of distortion, temperature, equivalent stress and yield stress. Hence, this paper focuses more on total distortion of the arm with chaining and unchaining process.

Table 5: Parameter of welding path

Number of path	Velocity (m/s)	Current [A]	Voltage [V]	Welding angle
1	0.01	220	26	y- axis/-74º
2	0.01	220	22	y-axis/69.6°
3	0.0083	230	26	y-axis/72.9°
4	0.0075	260	23	x-axis/118.4º
5	0.0075	260	23	x-axis/57.5º
6	0.0083	230	24	y-axis/-50.5º

Based on the table distortion for each of tracking points, it shows that the smaller is better because the distortion can affect the whole rear arm in terms of aesthetic value, material strength and properties. Table 6 shows the distortion data of chaining process and Table 7 represents the comparison data between chaining process and actual (experimental) part.

Table 6: Data of distortion for chaining process simulation

Tracking point	Distortion / End time (mm/s)
1	0.133/20.00
2	0.066/20.00
3	0.189/20.00

Table 7: Comparison between chaining process and actual

Tracking point	Chaining process	Actual distortion	Percentage of difference
1	0.133	0.123	7.5%
2	0.066	0.058	12.1%
3	0.189	0.162	14.3%

There are four selected sequences being simulated as unchained simulation process with the best sequence is the case one which is industrial sequence. They have lowest end total distortion which is good for assembly tolerance and average time for total distortion to reach minimum region, which is good for production time between different processes. Table 8, 9, 10 and 11 shows the simulated total distortions.

Table 8: Distortion value for 123456 welding sequence

Tracking point	Distortion / End time (mm/s)
1	1.6732 / 20.00
2	1.0051 / 20.00
3	2.6235 / 20.00

Table 9: Distortion value for 654321 welding sequence

Tracking point	Distortion / End time (mm/s)
1	3.3695 / 20.00
2	6.457 / 20.00
3	6.0163 / 20.00

Table 10: Distortion value for 214536 welding sequence

Tracking point	Distortion / End time (mm/s)
1	1.474 / 20.00
2	1.1558 / 20.00
3	0.5334 / 20.00

Table 11: Distortion value for 124536 welding sequence

Tracking point	Distortion / End time (mm/s)
1	0.2502 / 20.00
2	0.5905 / 20.00
3	0.2602 / 20.00

Based on the results above, 124536 welding sequence is used to compare with the actual results because of 124536 welding sequence is the most efficient results compared to the other sequence. The smaller value of distortion provides smaller percentage of error between the actual distortions. Table 12 presents the comparison data between unchaining process and actual (experimental) part in percentage of difference. Figure 8 shows the total distortion of its simulation.

Table 12: Comparison data between 124536 welding sequence and actual

Tracking point	124536 welding sequence	Actual distortion	Percentage of difference
1	0.133	0.123	7.5%
2	0.066	0.058	12.1%
3	0.189	0.162	14.3%

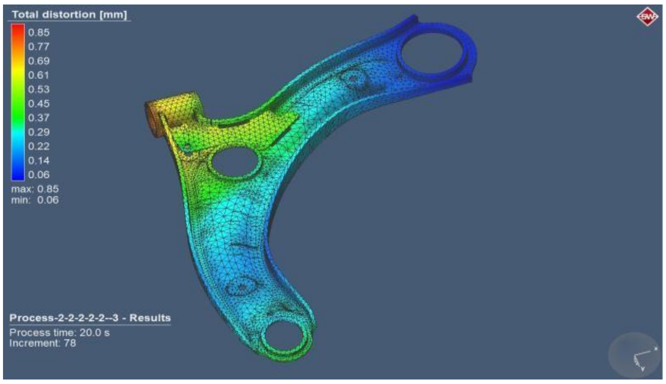

Fig. 8: Total distortion for 124536 welding sequences

From chaining and unchaining process, the data obtained then being compared with the distortion of actual distortion in actual rear arm. Table 13 and Table 14 show the comparison data between chaining and unchaining simulation. This paper provides an overview of the difference between these two processes. The data portrays chaining process give a huge impact in the final distortion compared to the unchaining process. Thus, analysis of chaining process using simulation is important in design optimization for industry.

Table 13: Comparison of all data with actual

Tracking point	Chaining process	Unchained process	Actual distortion
1	0.133	0.2502	0.123
2	0.066	0.5905	0.058
3	0.189	0.2602	0.162

Table 14: Comparison data between chaining and unchaining

Tracking point	Chaining process	Unchained process	Percentage of difference

1	0.133	0.2502	46.8%
2	0.066	0.5905	88.8%
3	0.189	0.2602	37.7%

4. Conclusion

The Process simulation for chaining and unchaining process has successfully conducted in this research. The finite element analysis using Simufact Welding method proved to be capable of demonstrating with high accuracy for estimation of the distortion of lower arm. This study breaks that the huge difference between chaining and unchaining process. Reflected from the previous study, the impact brought by this stamping process will be resulting the huge difference in distortion between these two processes. The results of chaining process can be better using this simulation. Chaining process analysis using simulation will give a better understanding about the product's mechanical properties or product's behavior, thus will be stated out the differences between these two elements. Any distortion failure that might be causing damages to the product can be avoided by using finite element method. Thus, there is high possibility that distortion failure will occur if this particular simulation is not being practiced. Hence, the rear arm designation can be further improvised which also including the design optimization as the chaining process is being practiced using simulation.

This paper explores distortion of the rear arm between two processes which is chaining and unchaining process. From this investigation, some conclusion arises as follows:

i. Percentage of error of distortion between chaining process and the actual rear arm for tracking points 1, 2 and 3 is 7.5%, 12.1% and 14.3% respectively.

ii. Percentage error of distortion between unchaining process and the actual rear arm for tracking points 1, 2 and 3 is 50.8%, 90.2% and 37.7% respectively.

iii. It portrays that chaining process has better value of distortion in terms of the smaller the value is the better. Simufact software implemented integrated simulation of the complete chain manufacturing processes, consequently the metal forming industry growing in receiving interest in coming years.

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