UNIVERSITI PUTRA MALAYSIA

TOOL DESIGN AND PARAMETER OPTIMIZATION FOR INCREMENTAL SHEET-FORMING PROCESS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

TO MY LOVELY PARENTS

AND

MY FAMILY

ABSTRACT

Abstract of thesis presented to the senate of Universiti Putra Malaysia
in fulfillment of the requirement for degree of master

TOOL DESIGN AND PARAMETERS OPTIMIZATION FOR INCREMENTAL SHEET FORMING PROCESS

By

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Incremental Sheet Forming (ISF) is a method developed to form a desired surface feature on sheet metals in batch production series. Due to lack of reliable data about the process, researchers are currently experimenting with the parameters to achieve the optimum process setting. In this work, ISF was carried out on stainless steel sheets using Computer Numerical Control (CNC) lathe and milling machines. Experiments were conducted to find out how the ISF process parameters i.e. tool material, spindle speed and feed rate, affect the quality of the part produced. Prior to running the experiments, a ball-point shaped tool made of bronze alloy was fabricated due to its superior ability to reduce the amount of friction and improve the surface quality of the stainless steel sheet compare to the aluminum-bronze and brass

alloy. The experiments employed the method of forming in negative direction with a blank mold and the tool that helped to shape the desired part quickly. The differences between the milling and lathe machine were also considered in this study and the results showed that the lathe machine was more efficient in terms of programming and the working time was reduced by 50% for circular parts. The programming was generated using the MasterCAM software for the CNC lathe machine and edited before transferring to the machine. However, the programming for the milling machine was written manually for simplicity. The amount of lubrication was also one the parameters of interest in this study but its effect on the part output was not significant, therefore, the amount used was kept constant about 250 CC throughout the experiments to avoid waste of lubricant. Besides that, the temperature of the contact area was measured and it showed that the amount never rose to more than 80°C which was still acceptable for ISF. From the results, the optimum spindle speed was found to be at 186 rpm and the optimum feed rate was 500 m/min.

ABSTRAK

Abstrak ini disediakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah master Sains

REKA BENTUK ALAT DAN PENGOPTIMUMAN PARAMETER UNTUK PROSES PEMBENTUKAN KEPINGAN TOKOKAN

Oleh

MAJID MOAYEDFAR

Februari 2013

Pengerusi: Prof. Madya Zulkiflle Bin Leman, PhD

Fakulti: Kejuruteraan

Pembentukan Kepingan Tokokan (ISF) adalah satu kaedah yang dibangunkan untuk membentuk ciri-ciri permukaan yang diingini pada kepingan logam dalam siri pengeluaran berkelompok. Disebabkan oleh kekurangan data yang boleh dipercayai tentang proses ini, penyelidik sedang menjalankan ujikaji terhadap parameter untuk mencapai parameter proses yang optimum. Dalam kajian ini, ISF telah dilakukan pada kepingan keluli tahan karat menggunakan mesin larik kawalan berangka komputer (CNC) dan mesin mencanai. Ujikaji telah dijalankan untuk mengetahui bagaimana parameter proses ISF iaitu bahan alat, kelajuan spindel dan kadar suapan, menjejaskan kualiti bahagian yang dihasilkan. Sebelum menjalankan eksperimen,

alat berbentuk bola mata bulat yang diperbuat daripada aloi gangsa direka kerana keupayaannya lebih baik untuk mengurangkan geseran dan meningkatkan kualiti permukaan kepingan keluli tahan karat berbanding dengan aloi aluminium-gangsa dan loyang. Eksperimen menggunakan cara yang membentuk arah negatif dengan acuan kosong dan alat yang membantu untuk membentuk bahagian yang diingini dengan cepat. Perbezaan antara mesin canai dan mesin larik juga telah diambil kira dalam kajian ini dan hasil kajian menunjukkan bahawa mesin larik lebih cekap dari segi pengaturcaraan dan masa kerja berkurangan sebanyak 50% bagi bahagian membulat. Pengaturcaraan yang dihasilkan menggunakan perisian MasterCAM untuk mesin larik dan diedit sebelum dipindahkan ke mesin. Walau bagaimanapun, pengaturcaraan untuk mesin canai telah ditulis secara manual kerana ia lebih mudah. Jumlah pelinciran juga merupakan salah satu parameter yang menarik dalam kajian ini tetapi kesan pada bahagian yang dikeluarkan adalah tidak ketara, oleh itu, jumlah yang digunakan adalah sentiasa malar about 250 CC sepanjang eksperimen untuk mengelakkan pembaziran pelincir. Selain itu, suhu kawasan sentuhan juga diukur dan ia menunjukkan bahawa ia yang tidak pernah meningkat kepada lebih daripada 80°C iaitu masih boleh diterima untuk ISF. Dari keputusan, kelajuan optimum spindel dijumpai pada 186 rpm dan kadar suapan yang optimum adalah 500 m/min.

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APRROVAL

I certify that a Thesis Examination Committee has met on February 28th in 2013 to conduct the final examination of Majid Moayedfar on his thesis entitled "Tool design and parameters optimization for incremental sheet forming process" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

MAJID MOAYEDFAR

Date: 28 February 2013

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LIST OF ABBREVIATIONS

.

ISF	Incremental sheet forming
CNC	Computer numerical controller
CAD	Computer aided design
TPIF	Two point incremental forming
SPIF	Single point incremental forming
CAM	Computer aided manufacturing
CATIA	Computer aided three dimensional interactive application
G codes	Go codes (linear movement)
M codes	Machine codes
TiN	Titanium Nitride
AISI 316	Stainless steel 316
AISA 304	Stainless steel 304
ASA	Atlas Steel Australia
Ti	Titanium
B	Boron
Al	Aluminum
SQ	Surface quality
Rm	Unit of Tensile strength
Rp	Unit of Yield stress
E	Young's modulus
A5	Elongation at break

HB	Brinell hardness
MPa	Mega Pascal
GPa	Giga Pascal
RPM	Revolution per minute
Cr	Chrome
Mo	Molybdenum
DNC	Direct numerical controller

CHAPTER 1

INTRODUCTION

1.1 Background

Incremental sheet forming (ISF) is a sheet metal forming technique where a sheet is formed into the final work piece by a series of small incremental deformations. However, studies have shown that it can be applied to polymer and composite sheets too. Generally, the sheet is formed by a round tipped tool, typically 5 to 20mm in diameter. The tool, which can be attached to a CNC machine, a robot arm or similar, indents into the sheet by about 1 mm and follows a contour for the desired part. It then indents further and draws the next contour for the part into the sheet and continues to do this until the full part is formed. ISF can be divided into variants depending on the number of contact points between tool, sheet and die (in case there is any). The term Single Point Incremental Forming (SPIF) is used when the opposite side of the sheet is supported by a faceplate and Two Point Incremental Forming (TPIF) when a full or partial die is supports the sheet.

Forming of sheet metal contains different methods which are based on the use of punches and dies. Conventional methods, like stamping and drawing are always used in mass production, but the high cost require primary investment and the total price for a sheet part in batch production rises, then the use of new sheet forming method becomes essential. Therefore, if a large quantity of products is not needed, the straight method does not have any value in the industry and the method of new production, namely incremental sheet forming, is introduced since 1960 to reduce the

cost of parts for low volume production. Nowadays, the low volume production and small batch series are more usable in a large number of industries (automotive and airplane industries, rapid prototyping, parts for medical implants) and ISF appears to be significant which fills this gap among the batch and the mass productions with less lead time and investment.

Recent survey in many of developed industrial companies shows some important factors which effect on the volume of production such as cost of production, initial investment, amount of benefit, environmental effect and brand corrosion (making bad effects on the reputation of a famous company trade mark) (Subramoniam et al., 2010). It will be great that the new method of production improves the total amount of items and change them to the applicable factors. Incremental sheet metal forming has numerous advantages which make this procedure more privileged.

Most of the automotive companies are looking for a technology that helps them to manufacture their new design even if it is a conceptual plan. One other important advantage of ISF is that the process is so quick and there is almost no lead time (Jeswiet et al., 2005). As mentioned before, another benefit of this process is the variety of products which help manufacturers to design a new plan upon the market, update their old design, check out the first plan in an actual part and check the final design by the material and without concentrating on their test or experiment costs. As it seems in the other literature since 1960, (Jeswiet et al., 2005) ISF has the ability to be used as a technique to show the importance of forming parameters in some parts of sheet forming process. It is even used as an experimental procedure to identify the mechanical characteristics of sheet metals in some stamping companies. Incremental

sheet forming has some advantages than two more important sheets forming processes; spinning and shear spinning, which are illustrated in the Table 1.1. In this part some of these advantages will be compared with other processes and proves that ISF is rather privileged to stamping in batch series. (Hadoush et al., 2011) and (Emmens et al., 2008)

Table 1.1: Comparison between spinning, shear spinning and ISF

	Spinning	Shear spinning	ISF
Blank edge	moves inwards	remains constant	clamped
Wall thickness	remains more or less constant	reduces, has to follow the sine law	reduces, determined by the process
Shape basically Determined by	movement of roller, or by mandrel	mandrel	movement of punch or roller
Die/Mandrel required	yes (acts as fixture)	yes	no
Asymmetric Shapes possible	limited	no	yes

1.2 Problem Statement

There are some parameters which are rather important in ISF than the other sheet forming process such as temperature, friction, feed rate, clamping force, tool path and tool shape.

Some of the articles research on tool path (Bambach et al., 2009; Hirt et al., 2005) and some others worked on simulation of the process (Bambach et al., 2005; Hadoush et al., 2009b). In addition, there are some other important parameters in the forming process which changing of them would change the whole part of the experiment. One of these parameters is the tool coordinate. Since the tool coordination in this process is simpler than other sheet forming process, the shape of tools in ISF has changed that called tool's shape. Previous tools used a simple indenter that moves toward the clamped sheet and the movements of the tool were dictated by CNC milling machine program which completes the final shape. In some different experiments an indenter was fastened on a robot actuator and was forced point by point on the surface of the sheet. None of these methods could give the customers a reasonable final surface quality. Moreover, the accuracy of final shape was different from the one which was designed by the CAD software. The reason was because of the spring back phenomena and temperature effect.

The indenter is a simple tool; a long shank with a narrow neck and a hemispherical head. These tools are in different sizes but do not have different shapes. It is obvious that the simpler tool is more desirable but because of low range of pre-fabrication and variety of shape will be problematic in final shape that needs all kind of head

geometry and also it does not have any special effect on the characteristics of ultimate parts. The indenter has some characteristics itself as a forming tool. If the simple indenter is not wear resistant, it will be deformed during the experiment and if it is not heat treated, it would not be tough enough and cannot decrease the effect of friction which causes the corrosion on the sheet surface resulting in sheet failure or unacceptable surface of the final part.

1.3 Aims and Objectives

ISF is a process which like other new technical procedure has some limitations such as the volume of products, shape of sheet metal parts and surface quality. As mentioned in previous section, indenters are not as complete as the tool to be used in an industrial application. The design and manufacture of these kinds of tools are simple but do not have any appropriate results, so the goals of this research are:

1- To design a conceptual tool for ISF to present as an applicable indenter.
2- To determine the optimum parameters of ISF in using CNC lathe and milling machine.

1.4 Research Scope

Incremental sheet forming is on the procedure of upgrading to solve the production's problems in batch series or even sometimes solve the problems of the sheet metal forming process. There are a lot of parameters that can affect the quality of products which should be improved. New parameters are in need which can just manage a new process. This study is mostly concentrated on the tool shape which is used in ISF and tried to show some valid data for further activities.

During all the experiments, some parameters were fixed such as the sheet metal which is stainless steel 316 that has 1mm thickness. Also the clamping force did not change during the experiment so the experiment is focused on the parameters that can be adjusted by the tool and the machine. Other parameters such as sheet clamp, tool path, simulation of process and some other important parameters for ISF have not been considered but it would be recommended for future research.

Also in this study worked only on stainless steel L316 sheet metal (AISI 316). In addition, for forming process a CNC lathe machine and a CNC milling machine is employed. Therefore, the study is contained with using a CNC machine to shape the stainless steel sheet metal with an indenter. During this process some parameters for forming process can be found and also the optimum tool material, spindle speed, feedrate and temperature are considered. Moreover, the optimum parameter are generated some figures to be standardized for future work.

REFERENCES

Aerens, R., Eyckens, P., Van Bael, A. & Duflou, J. R. (2010). Force prediction for single point incremental forming deduced from experimental and FEM observations. *The International Journal of Advanced Manufacturing Technology, 46*(9), 969-982.

Allwood, J., Braun, D. & Music, O. (2010). The effect of partially cut-out blanks on geometric accuracy in incremental sheet forming. *Journal of materials processing technology, 210*(11), 1501-1510.

Allwood, J. & Shouler, D.R. (2007). Paddle forming: a novel class of sheet metal forming processes. *CIRP Annals-Manufacturing Technology, 56*(1), 257-260.

Ambrogio, G., Bruschi, S., Ghiotti, A. & Filice, L. (2009a). Formability of AZ31 magnesium alloy in warm incremental forming process. *International Journal of Material Forming, 2(10)*, 5-8.

Ambrogio, G., De Napoli, L. & Filice, L. (2009b). A novel approach based on multiple back-drawing incremental forming to reduce geometry deviation. *International Journal of Material Forming, 2(7)*, 9-12.

Ambrogio, G., De Napoli, L. & Filice, L. (2010). Prediction of incremental sheet forming process performance by using a neural network approach. *The International Journal of Advanced Manufacturing Technology, 54*(9), 921-930.

Ambrogio, G., Filice, L. & Manco, G.L. (2008b). Considerations on the Incremental Forming of Deep Geometries. *International Journal of Material Forming, 1*, 1143-1146.

Attanasio, A., Ceretti, E., Giardini, C. & Mazzonia, L. (2008). Asymmetric two points incremental forming: Improving surface quality and geometric accuracy by tool path optimization. *Journal of materials processing technology, 197*(1-3), 59-67.

Bambach, M. (2010). A geometrical model of the kinematics of incremental sheet forming for the prediction of membrane strains and sheet thickness. *Journal of materials processing technology, 210*(12), 1562-1573.

Bambach, M., Cannamela, M., Azaouzi, M., Hirt, G. & Batoz, J.L. (2007). Computer-aided tool path optimization for single point incremental sheet forming. *Advanced Methods in Material Forming, Springer*, 233-250.

Bambach, M. & Hirt, G. (2005). *Performance Assessment of Element Formulations and Constitutive Laws for the Simulation of Incremental Sheet Forming (ISF)*.

Bambach, M., Taleb Araghi, B. & Hirt, G. (2009). Strategies to improve the geometric accuracy in asymmetric single point incremental forming. *Production Engineering, 3*(2), 145-156.

Bouffioux, C., Cannamela, M. & Azaouzi, M. (2008). Identification of material parameters to predict Single Point Incremental Forming forces. *International Journal of Material Forming, 1*, 1147-1150.

Bouffioux, C., Pouteau, P., Duchêne L., Vanhove, H., Duflou, J.R. & Habraken, A.M. (2010). Material data identification to model the single point incremental forming process. *International Journal of Material Forming, 3*, 979-982.

Cerro, I., Maidagan, E., Arana, J., Rivero, A. & Rodr´ıguez, P. (2006). Theoretical and experimental analysis of the dieless incremental sheet forming process. *Journal of materials processing technology, 177*(1), 404-408.

Dejardin, S., Thibaud, S., Gelin, J.C. & Michel, G. (2008). Finite element analysis and experimental investigations for improving precision in single point incremental sheet forming process. *International Journal of Material Forming, 1*, 121-124.

Dejardin, S., Lauwers, B. & Verbert, J. (2009). Experimental investigations and numerical analysis for improving knowledge of incremental sheet forming process for sheet metal parts. *Journal of materials processing technology, 210*(2), 363-369.

Duflou, J., Callebaut, B., Verbert, J. & De Baerdemaeker, H. (2007a). Laser assisted incremental forming: formability and accuracy improvement. *CIRP Annals-Manufacturing Technology*, *56*(1), 273-276.

Duflou, J., Lauwers, B. & Verbert, J. (2007b). Study on the achievable accuracy in single point incremental forming. *Advanced Methods in Material Forming*, 251.

Duflou, J., Vanhove , H., Verbert, J., Gu, J., Vasilakos, I. & Eyckens, P. (2010). Twist revisited: Twist phenomena in single point incremental forming. *CIRP Annals-Manufacturing Technology, 59*(1), 307-310.

Emmens, W., Sebastiani, G. & Van Den Boogaard, A.H. (2010). The technology of Incremental Sheet Forming--A brief review of the history. *Journal of materials processing technology, 210*(8), 981-997.

Emmens, W. & Van Den Boogaard, A.H. (2008). Tensile tests with bending: a mechanism for incremental forming. *International Journal of Material Forming, 1*, 1155-1158.

Emmens, W. & Van Den Boogaard, A.H. (2009a). Incremental forming by continuous bending under tensionâ€"An experimental investigation. *Journal of materials processing technology, 209*(14), 5456-5463.

Emmens, W. & Van Den Boogaard, A.H. (2009b). An overview of stabilizing deformation mechanisms in incremental sheet forming. *Journal of materials processing technology*, *209*(8), 3688-3695.

Essa, K. & Hartley, P. (2009). An assessment of various process strategies for improving precision in single point incremental forming. *International Journal of Material Forming*, 1-12.

Eyckens, P., Belkassem, B. & Henrard, C. (2011). Strain evolution in the single point incremental forming process: digital image correlation measurement and finite element prediction. *International Journal of Material Forming*, *4*(1), 55-71.

Eyckens, P., Duflou, J., Van Bael, A. & Houtte, P. (2010). The significance of friction in the single point incremental forming process. *International Journal of Material Forming, 3*, 947-950.

Fiorotto, M. & Van Den Boogaard, A.H. (2010). Preliminary studies on single point incremental forming for composite materials. *International Journal of Material Forming, 3*, 951-954.

Franzen, V., Kwiatkowski, L., Sebastiani, G., Shankar, R., Tekkaya, A. E. & Kleiner, M. (2008). Dyna-Die: Towards full kinematic incremental forming. *International Journal of Material Forming, 1*, 1163-1166.

Gottmann, A., Diettrich, J. & Bergweiler, G. (2009). Laser-assisted asymmetric incremental sheet forming of titanium sheet metal parts. *Production Engineering, 5*(3), 263-271.

Hadoush, A. & Van Den Boogaard, A.H. (2008). Time reduction in implicit single point incremental sheet forming simulation by refinement-derefinement. *International Journal of Material Forming, 1*, 1167-1170.

Hadoush, A. & Van Den Boogaard, A.H. (2009a). On the performance of substructuring implicit simulation of single point incremental forming. *International Journal of Material Forming, 2*, 559-562.

Hadoush, A. & Van Den Boogaard, A.H. (2009b). Substructuring in the implicit simulation of single point incremental sheet forming. *International Journal of Material Forming, 2*(3), 181-189.

Hadoush, A., Van Den Boogaard, A.H. & Emmensc, W.C. (2011). A numerical investigation of the continuous bending under tension test. *Journal of materials processing technology*, 11(15), 425-429.

Held, C., Sindel, M. & Liewald, M. (2010). Novel Semi-Empirical Model for Forming Limit Prediction of Sheet Metal Material with Regard on Effects of Shear-Tension Loads. *International Journal of Material Forming, 3*, 1171-1174.

Henrard, C. (2011). Forming forces in single point incremental forming: prediction by finite element simulations, validation and sensitivity. *Computational Mechanics, 47*(5), 573-590.

Hirt, G., Ames, J., Bambach, M. & Kopp, R. (2005). Forming strategies and process modelling for CNC incremental sheet forming. *CIRP Annals-Manufacturing Technology, 53*(1), 203-206.

Hisham, M. (2009). *Analysis and optimization machining parameter base on different type of material in incremental forming process (ALGOR simulation).* Universiti Malaysia Pahang.

Hussain, G., Lin, G. & Hayat, N. (2011). Improving profile accuracy in SPIF process through statistical optimization of forming parameters. *Journal of Mechanical Science and Technology, 25*(1), 177-182.

Jackson, K., Allwood, J.M. & Landert, M. (2009). The mechanics of incremental sheet forming. *Journal of materials processing technology, 209*(3), 1158-1174.

Jackson, K. & Allwood, J. (2008). Incremental forming of sandwich panels. *Journal of materials processing technology, 204*(1), 290-303.

Jeswiet, J., Micari, F., Hirt, G., Bramley, A., Duflou, J. & Allwood, J. (2005). Asymmetric single point incremental forming of sheet metal. *CIRP Annals-Manufacturing Technology, 54*(2), 88-114.

Jurisevic, B., Kuzman, K. & Junkar, M. (2006). Water jetting technology: an alternative in incremental sheet metal forming. *The International Journal of Advanced Manufacturing Technology, 31*(1), 18-23.

Katajarinne, T., Vihtonen, L. & Kivivuori, S. (2008). Incremental forming of colour-coated sheets. *International Journal of Material Forming, 1*, 1175-1178.

Kim, S., Lee, Y. S., Kang S. H. & Lee, H. (2007). Incremental forming of Mg alloy sheet at elevated temperatures. *Journal of Mechanical Science and Technology, 21*(10), 1518-1522.

Korhonen, A., Manninen, T., Yoon, J.W. & Larkwola, J. (2009). Comparsion of forming and fracture limits of an aluminum alloy and austenitic stainless steel. *International Journal of Material Forming, 2*, 431-434.

Kwiatkowski, L., Urban, M. & Sebastiani, G. (2010). Tooling concepts to speed up incremental sheet forming. *Production Engineering, 4*(1), 57-64.

Luo, Y., He, K. & Du, R., (2010). A new sheet metal forming system based on incremental punching, part 2: machine building and experiment results. *The International Journal of Advanced Manufacturing Technology, 51*(5), 493-506.

Masuku, E., Bramley, A. N. & Mileham, A. R. (2005). Incremental Sheet Metal Forming: A Die-Less Rapid Prototyping Process for Sheetmetal. *Advances in integrated design and manufacturing in mechanical engineering*, 305-314.

Moayedfar, M. (2007). *Incremental sheet forming* Applied science Esfahan. A project presented to the university training Tohid.

Nguyen, D. T., Jin-Gee, P. & Young-Suk, K. (2010). Ductile fracture prediction in rotational incremental forming for magnesium alloy sheets using combined kinematic/isotropic hardening model. *Metallurgical and Materials Transactions A, 41*(8), 1983-1994.

Odenberger, E. L. (2011). Tool development based on modelling and simulation of hot sheet metal forming of Ti-6Al-4 V titanium alloy. *Journal of materials processing technology*, 7(14), 425-432.

Oleksik, V., Bologa, O., Breaz, R. & Racz, G. (2008). Comparison between the numerical simulations of incremental sheet forming and conventional stretch forming process. *International Journal of Material Forming, 1*, 1187-1190.

Oleksik, V., Bologa, O. & Breaz, R. (2010). Experimental study on the surface quality of the medical implants obtained by single point incremental forming. *International Journal of Material Forming, 3*, 935-938.

Petek, A., Kuzman, K. & Kopaè, J. (2009). Deformations and forces analysis of single point incremental sheet metal forming. *Archives of Materials Science, 108*, 108.

Puzik, A. (2008). Incremental Sheet Forming with a Robot System for an Industrial Application. *Manufacturing Systems and Technologies for the New Frontier*, 421-424.

Rauch, M., Hascoet, J.Y., Hamann, J.C. & Plennel, Y. (2009). Tool path programming optimization for incremental sheet forming applications. *Computer-Aided Design, 41*(12), 877-885.

Rauch, M. (2008). A new approach for toolpath programming in Incremental Sheet Forming. *International Journal of Material Forming, 1*, 1191-1194.

Robert, C., Dal Santo, P., Delamézière, A., Potiron, A. & Batoz, L. (2010). Development of a simplified approach of contact for incremental sheet forming. *International Journal of Material Forming, 3*, 987-990.

Robert, C. (2008). On some computational aspects for incremental sheet metal forming simulations. *International Journal of Material Forming, 1*, 1195-1198.

Schafer, T. & Schraft, R. D. (2005). Incremental sheet metal forming by industrial robots. *Rapid Prototyping Journal, 11*(5), 278-286.

Schneider, T. & Merklein, M. (2011). Sheet-Bulk Metal Forming of Preformed Sheet Metal Parts. *Key Engineering Materials, 473*, 83-90.

Silva, M. (2008). Single point incremental forming and formability on failure diagrams. *The Journal of Strain Analysis for Engineering Design*, *43*(1), 15-35.

Skjodt, M., Bay, N., Endelt, B. & Ingarao, G. (2008). Multi stage strategies for single point incremental forming of a cup. *International Journal of Material Forming, 1*, 1199-1202.

Subramoniam, R., Huisingh, D. & Chinnam, R.B. (2010). Aftermarket remanufacturing strategic planning decision-making framework: theory & practice. *Journal of Cleaner Production, 18*(16-17), 1575-1586.

Tekkaya, A. E. (2007). Surface reconstruction for incremental forming. *Production Engineering, 1*(1), 71-78.

Tisza, M., Panity, I. & Kovács, P. Z. (2011). Experimental and numerical study of a milling machine-based dieless incremental sheet forming. *International Journal of Material Forming, 3*, 971-974.

Vanhove, H. (2010). An experimental study of twist phenomena in single point incremental forming. *International Journal of Material Forming, 3*, 975-978.

Verbert, J. (2008). Multi-Step toolpath approach to overcome forming limitations in single point incremental forming. *International Journal of Material Forming, 1*, 1203-1206.

Vihtonen, L., Puzik, A. & Katajarinne,T. (2008). Comparing two robot assisted incremental forming methods: incremental forming by pressing and incremental hammering. *International Journal of Material Forming, 1*, 1207-1210.

Welo, T. (2008). Sheet metal forming in a prototyping method of ISF. *Journal of Advances in Material Forming*, 175-191.

Yang, H. (2011). Recent developments in plastic forming technology of titanium alloys. *SCIENCE CHINA Technological Sciences, 54*(2), 490-501.

Zhu, H., Li, N. & Liu, Z. J. (2011). The effect of pressing direction on the 5-axis CNC incremental forming quality. *International Journal of Material Forming*, 1-7.