Proceedings of International Conference on Mechanical & Manufacturing Engineering (ICME2008), 21– 23 May 2008, Johor Bahru, Malaysia.

ISBN: 97–98 –2963–59–2

Conceptual Design of a Spiral Catalyst Support

Mohd Fahrul bin Hassan[1], Darwin Sebayang[1]
[1]Faculty of Mechanical and Manufacturing Engineering
Tun Hussein Onn University of Malaysia (UTHM)
Parit Raja, Batu Pahat, 86400 Johor,
Malaysia
fahrul@uthm.edu.my , darwin@uthm.edu.my

Abstract:
Spiral catalyst support is one of the substrate types for catalytic converter which reduces the harmful emissions from the combustion engines. Currently, an issue of considerable interest is to design a catalyst support which can increase the performance of catalytic converter. Consequently, three patents developed in recent years for the development of spiral catalyst support, which produces a mandrel as an apparatus to provide a structure which prevents telescoping of the layers of a spiral catalyst support and two methods for manufacturing the spiral catalyst support, welding multi-points and heat treatment of metals. The aim of this paper is to present the alternative of an innovative tool to develop a spiral catalyst support based on Pahl and Beitz model of design process. The conceptual design was used to generate principle solutions and optimize the design concepts of an innovative spiral tool development as a forming tool to form a sheet metal in spiral form. The spiral form was successfully produced by an innovative spiral tool without considering the springback behaviors.

Key Words: Spiral catalyst support, Conceptual design.

1. Introduction

Catalytic converters have become the universal solution for vehicles to comply with the emission regulation**.** The catalytic converter which is installed in the exhaust line of vehicles, between the exhaust manifold and the muffler consists of an insulated chamber containing a catalyst support, coated with catalytic material through which hot exhaust gases must pass before being discharged into the air.

The function of the catalyst support is to act as a carrier for the washcoat and for the noble-metal oxidizing catalyst [1]. The catalytic converters with metallic type catalyst supports have seen ever-wider acceptance because of several advantages over conventional ceramic-based converters [2]. One of the advantages of metallic catalyst support is a thinner substrate wall (30 to 50 microns) which provides lower backpressure and smaller package [3]. Nowadays, increasing the cell density and decreasing the wall thickness have been demanded requirement in producing of catalyst support. Several experimental studies have shown that the converter performance can be improved by reducing the bulk density and increasing the geometric surface area of the catalyst support [1, 4, 5, 6, 7].

An issue of considerable interest is the design of catalyst support which can increase the performance of catalytic converter. Some of the studies have being carried out to investigate the effects of catalyst support on catalytic converter performances, both on simulation [4, 6, 7] and experimentally [1, 3, 8, 9]. Since, the effectiveness of the catalyst support is particularly dependent on a number of factors including its shape, size, material

Proceedings of International Conference on Mechanical & Manufacturing Engineering (ICME2008), 21– 23 May 2008, Johor Bahru, Malaysia.

ISBN: 97–98 –2963–59–2

and others, which make the analysis and manufacturing extremely difficult.

Although researches on catalyst support in terms of its shape capability, design improvement, material selection, geometric surface area, durability and resistance had blossomed and are widely discussed in literature but the research on manufacturing of sheet metal for the catalyst support is limited. There are three patents related to the research progress are recognized where the patents are focusing on catalyst support of catalytic converter making [10, 11, 12]. Furthermore, these patents studied on manufacturing of catalyst support by applying a different methods and apparatus in order to form a sheet metal in spiral form. A mandrel as an apparatus was produced by Retallick [12] to provide a structure which prevents telescoping of the layers of the spiral catalyst support. The invention does not require brazing of a metal and also includes a method of making the catalyst support. Matsuo et al [11] patented the method of welding multi-points for a short time to produce a spiral catalyst support structure while Solntsev et al [10] introduced a method for manufacturing such structures by heat treatment of metals. The researches of these patents are performed by experimental test only without any systematic approach of conceptual design.

Therefore, this paper presents a manufacturing of a spiral catalyst support by innovative spiral tool with the systematic approach of conceptual design.

2. The Systematic Approach of Design Process

Design process is a process used by engineers to help in developing products. This study is focused on the conceptual design for manufacturing of catalyst support in spiral form based on the Pahl and Beitz model of design process [13]. At the conceptual design phase, there are several particular descriptions have to consider in design process.

3. Patented Specifications of Catalyst Support

Catalyst support specifications on the previous patents were summarized as in Table 1 to show the basic data and information about the designed configurations.

Table 1: Summarization of patented catalyst support specifications

		Thin-Walled Monolithic Metal Oxide Structures made from Metals,and Methods for Manufacturing such Structures, Sointsev et al [9].	Multi-Point Welding Method and Catalyst Support Produced Thereby, Matsuo et al [11].	Apparatus for Shaping a Spiral Catalyst Support, Retallick [14].
	Type	Metallic	Metallic	Metallic
	Material	Iron oxide structure	Ferritic heat resisting stainless steel	Any type of metals
	Form of materials	Flat & Corrugated	Flat & Corrugated	Flat & Corrugated
	Design structure	Spiral form	Spiral form	Spiral form
The size of the structures	Diameter (mm)	50 - 125	77	X
	Length (mm)	35 - 150	105	X
	The thickness of the flat sheets (mm)	0.025 - 0.1	0.05	X
	The thickness of the corrugated sheets (mm)	0.025 - 0.3	0.05	X
	Shape of cells	Triangular	Honeycomb	Honeycomb
The cell structure	Cell base (mm)	1.4 - 2.2	0.8 - 1.25	X
	Cell height (mm)	0.7 - 0.8	X	X
	Cell density (cpsi)	250 - 1000	X	X
Manufacturing method	Joining method	Heat treatment	Multi-Point Welding Method	X
	Apparatus for shaping a catalyst	X	X	Mandrel

X = Unspecified

Proceedings of International Conference on Mechanical & Manufacturing Engineering (ICME2008), 21– 23 May 2008, Johor Bahru, Malaysia.

ISBN: 97–98 –2963–59–2

4. Manufacturing Review of Previous Patents

Based on the summarization of previous patents, the manufacturing methods has been reviewed to make a comparison for each patents which are consist of method used, background of the invention and manufacturing process as in the following Table 2.

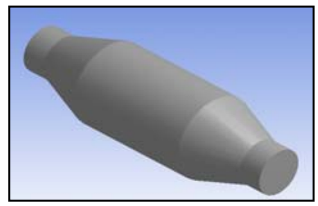
Table 2: Manufacturing review of previous patents

		Thin-Walled Monolithic Metal Oxide Structures made from Metals,and Methods for Manufacturing such Structures, Sointsev et al [9].	Multi-Point Welding Method and Catalyst Support Produced Thereby, Matsuo et al [11].	Apparatus for Shaping a Spiral Catalyst Support, Retallick [14].
Manufacturing review	Method	Heat treatment	Multi-point welding method	A mandrel
	Background	1) Capable of providing refractory characteristics such as are required in demanding temp. and chemical environments. 2) Having a variety of shapes and wall thickness.	1) In the catalyst support, the flat sheet needs to be welded to the corrugated sheet for preventing separation thereform. 2) To provide a multi-point welding method wherein multi-points to be welded are certainly welded for a short time.	1) Provides a structure which prevents telescoping of the layers of a spiral catalyst support. 2) Does not require brazing of the metal, so that any metal can be used.
	Process	1) The disk comprises a first flat sheet of steel adjacent a second corrugated sheet of steel, forming a triangular cell (mesh),which are rolled together to form a disk of suitable diameter. 2) Heating the metal-containing structure to a temperature below the melting point of metal to form a monolithic metal oxide structure having substantially the same shape.	1) Forming an approximately cylindrical base body by alternately laminating a metal made flat sheet and a metal made corrugated sheet. 2) Winding them in a spiral shape. 3) Mounting an electrode apart from one end surface of the base body. 4) Generating electric discharges to fuse and join the contact points of the flat sheet to the corrugated sheet.	1) The catalyst support is made by first winding a flat and a corrugated metal strip to form a spiral-shaped structure. 2) The strips are wound together on a mandrel, which is removed after the winding, to leave an axial hole 3) The structure, after being inserted into a cylindrical tube, is flattened at each end, and to provide a continuously tapered catalyst support. 4) The tapers in the support insure that the layers of the spiral cannot telescope outwardly in either direction.

5. Current Status of Catalytic Converter Development

5.1 Catalytic converter layout

The specifications of designed catalytic converter are shown in Figure 1 which is referred to Shahrin et al [14]. This layout has a suitability to have the maximum performance of honeycomb based on the temperature drop and velocity drop that were obtained.



Preliminary layout of catalytic converter	
Overall Length	300 mm
Inlet& outlet pipe diameter	48 mm
Substrate diameter	150 mm

Figure 1: The general layout of catalytic converter

5.2 Substrate of catalytic converter

Several parameters are needed to be identified to finalize the substrate design such as cell shape, length, wall thickness, cell density and total substrate diameter. Table 3 shows the specification of designed catalyst support according to previous paper [15].

Table 3: The specification of designed catalyst support

	Type	Metallic
	Material	FeCrAl
	Form of materials	Flat & Corrugated
	Design structure	Spiral form
The size of the structures	Diameter (mm)	150
	Length (mm)	133
	The thickness of the flat sheets (mm)	0.15
	The thickness of the corrugated sheets (mm)	0.15
	Shape of cells	Trapezoidal
The cell structure	Cell base (mm)	0.95
	Cell height (mm)	0.95
	Cell density (cpsi)	600 - 1000

Proceedings of International Conference on Mechanical & Manufacturing Engineering (ICME2008), 21– 23 May 2008, Johor Bahru, Malaysia.
© Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia.
ISBN: 97–98 –2963–59–2

6. Conceptual Design of an Innovative Spiral Tool

The research has been continued by manufacturing a catalyst support in spiral form by producing an innovative spiral tool. The first step is to concentrate on what has to be achieved by the design, and not how it is to be achieved. The basic way of expressing this is to represent the product as simply a 'black box' which converts certain inputs into desired output as in Fig. 2. The function analysis of the spiral tool is outlined in Figure 3.

Figure 2: Black box model of a spiral tool

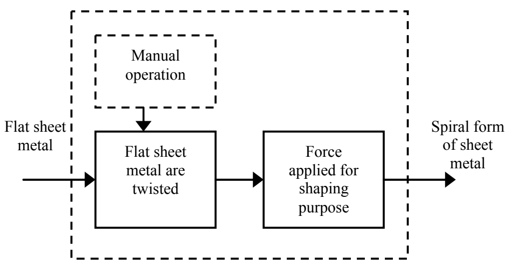


Figure 3: Function analysis of the spiral tool

Bending is a process by which the shape of the metal can be permanently changed by plastically deforming the material. The material is stressed beyond the yield strength but below the ultimate tensile strength. As in the plastic region, the formula will be used is

$$\sigma = K\varepsilon^{n} , \qquad (1)$$

where σ is the true stress, K is the strength coefficient, ε is the true strain and *n* is the exponent coefficient which the value of *n* will shows the strain to which a material can be stretched before necking begins.

Some of the questions exist and need to find out the solutions, there are 1) How the sheet metal can be formed into spiral form? 2) How the force can be applied? 3) How the bending process can be achieved into plastic region? And (4) How the springback problem will be solved?.

7. Principle Solution

In this phase, the solutions were listed out and evaluated. The generation of solutions is of course the essential and central aspect of designing. The principle solutions of an innovative spiral tool were listed in Figure 4. Basically, there are two sub-functions need to find out the best solution of the questions (1), (2) and (3) while the question (4) will be discussed later on the next step.

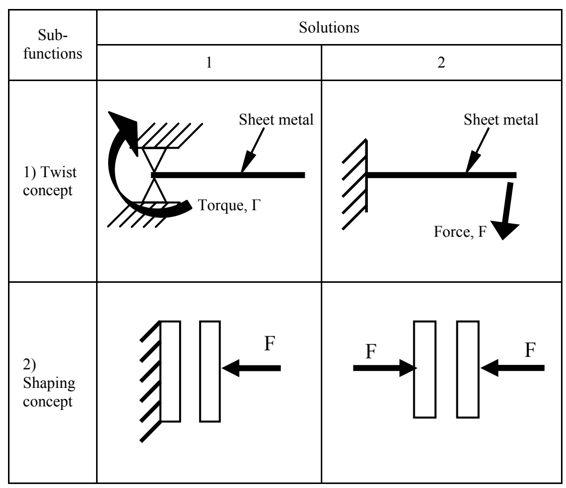


Figure 4: Principle solutions of an innovative spiral tool development

8. Results and Discussion

The mechanical properties of the sheet metal which obtained from tensile test can be seen in Table 4. This data shows the material formability as the first step of forming process.

Table 4: Mechanical properties of sheet metal

Youngs Modulus E (MPa)	Shear Modulus G (GPa)	Yield Stress (MPa)	Ultimate Stress (MPa)	Fracture Stress (MPa)	Elongation until break (mm)	Elongation (%)
26976	10.54	350.74	450.89	217.78	4.42	16.90

ISBN: 97–98 –2963–59–2

The principle solution of an innovative spiral tool was taken seriously in order to meet the best solution to form a sheet metal in spiral form. Therefore, to achieve this objective, an innovative spiral tool was developed from the combination of the best alternative principle solution, which solution 1 for twist concept and solution 2 for shaping concept.

The forming of the sheet metal is involving a bending process which will be faced a springback problem. However, without considering the springback behaviors, the selected principle solution of an innovative spiral tool has been applied to a sheet metal. The sheet metal was twisted by human force while 100N of spring force was applied for the shaping purpose. Figure 5 shows the model of spiral form produced by an innovative spiral tool.

Figure 5: The model of spiral form

9. Conclusion

The conceptual design of manufacturing the catalyst support in spiral form had achieved the initial step based on the Pahl and Beitz model of design process. Moreover, an innovative spiral tool has successfully produced the spiral form from a sheet metal.

For the next step, the selected design solution will be discussed in detail in terms of dimension, material selection and fabrication process. The manufacturing of spiral catalyst support will be aided by using Finite Element Method (FEM) software as a prediction of sheet metal formability.

10. Acknowledgment

The authors wish to acknowledge the funding supported by Fundamental Research Grant Scheme, Vot 0153 and Short term Grant, Vot 0311.

11. References

[1] Umehara, K., Yamada, T., Hijikata, T., Ichikawa, Y. and Katsube, F. "Effective catalyst layout for ultra thin-wall and high cell-density ceramic substrate", SAE International paper No. 973118, 1997

[2] Tanaka, M., Ito, M., Makino, M. and Abe, F. "Influence of Cell Shape between Square and Hexagonal Cells", SAE Journals, 2003.

[3] Chang, C., Chen, L. and Jha, B. "Oxidation Induced Length Change of Thin Gauge Fe-Cr-Al Alloys', in Hans Bode, 'Material Aspects in Automotive Catalytic Converters" Deutsche Gesellschaft: Willey-vch 71-82, 2001.

[4] Muller-Haas, K. and Rice, M. "Innovative Metallic Substrates for Exhaust Emission Challenges for Gasoline and Diesel Engines" SAE Jounals, 2005-01-3851, 2005.

[5] Bollig, M., Liebl, J., Zimmer, R., Kraum, M., Seel, O., Siemund, S., Bruck, R., Diringer, J. and Maus, W. "Next Generation Catalysts are Turbulent: Development of Support and Coating", SAE Journals, 2004-01-1488, 2004.

[6] Shamim, T. and Shen, H. "Effect of Geometric Parameters on the Performance of Automotive Catalytic Converters", International Journal of Science and Technology 14, 15-22, 2003.

[7] Lylykangas, R. and Tuomala, H. "A New Type of Metallic Substrate" in

ISBN: 97–98 –2963–59–2

Hans Bode. "Material Aspects in Automotive Catalytic Converters", Deutsche Gesellschaft: Willey-vch 152-170, 2001.

[8] Campbell, M.G. and Martin, E.P. "Substrate Selection for a Diesel Catalyst", International Congress and Exposition Detroit, Michigan., SAE Journal, 950372, 1995.

[9] Swiatek, G. and Rudnicki, R. "Catalytic Exhaust Emission Control of Small Internal Combustion Engines", Small Engine Technology Conference Milwaukee, Wisconsin. SAE Journal 891799, 1989.

[10] Solntsev, K., Shustorovich, E., Myasoedov, S., Morgunov, V., Chernyavsky, A., Buslaev, Y and Montano, R. "Thin-Walled Monolithic Metal Oxide Structures Made From Metals, and Method for Manufacturing Such Structures", United States Patent No. 6,051,203, 2000.

[11] Matsuo, K., Yokoi, M., Kawabe, Y., Hashimoto, I. and Ito, K. "Multi-Point Welding Method and Catalyst Support Produced Thereby", United States Patent No. 5,391,851, 1995.

[12] Retallic, W.B. "Apparatus for Shaping a Spiral Catalyst Support", United States Patent No. 4,677,839, 1987.

[13] Cross, N. "Engineering Design Method Strategies for Product Design", John Wiley & Sons Ltd, 3rd Edition, 2000.

[14] Darwin Sebayang, Puji Untoro, Hamimah Abd. Rahman, Shahrin Hisham. "Conceptual Design of Catalytic Converter." International Advanced Technology Congress 2005.

[15] Shahrin, H. A., Darwin, S., Hamimah, A. B. and Pudji, U. "Development of an Innovative Three Way Catalytic Converter – Effort and Challenge", World Engineering Congress 2007, Penang, 2007.

[16] Presti, M., Pace, L. and Hodgson, J. "A computational and Experimental Analysis for Optimization of Cell Shape in High Performance Catalytic Converters", SAE Journals, 2002.

[17] Buranathiti, T. and Cao, J. "An effective amalytical model for springback prediction in straight flanging process", Int. J. Materials and Product Technology, Vol. 21, 2004.

[18] Yoshida, T., Hashimoto, K., Katayama, T. and Kuriyama, Y. "Shape Control Techniques for High Strength Steel in Sheet Metal Forming", Nippon Steel Technical Report No.88, 2003.