Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 63 (2013) 346 – 353

Procedia Engineering

www.elsevier.com/locate/procedia

The Manufacturing Engineering Society International Conference, MESIC 2013

The effect of process parameters on the energy consumption in Single Point Incremental Forming

I. Bagudanch[a,*], M.L. Garcia-Romeu[a], I. Ferrer[a], J. Lupiañez[a]

[a]*Mechanical Engineering and Industrial Construction Department. Campus Montilivi, University of Girona. 17071 Girona, Spain*

Abstract

Recently, environmental and sustainability concerns have gathered considerable attention in the academic world. Some contributions have been made in this field, but for manufacturing processes, and specially for forming processes this concern has just begun. For this reason, in the present work the influence of the variation of several process parameters in Single Point Incremental Sheet forming has been carried out. Thus, a campaign of experiments with its corresponding statistical analysis has been done. The calculation of CO_2 emissions for the ISF-formed part, under the Spanish framework, has been also carried out. Spindle speed variation is the most significant parameter, followed by the material and incremental step. From results, an improvement of the combination of process parameters in order to minimize energy consumption will be possible.

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion

Keywords: Incremental Sheet Forming; Energy consumption; Environmental footprint; Environmental analysis

1. Introduction

Through the years, manufacturing processes have been analyzed under several points of view. One of the most recent is related to the world concern on environmental and sustainability issues. In the literature (Ingarao et al., 2011; Duflou et al., 2011; Anghinelli et al., 2011), it is recognized that there exist a lack regarding these issues in manufacturing processes. Especially this lack is even more important in sheet metal forming processes due to its inherent process dependent feature (Ingarao et al., 2011).

* Corresponding author. *E-mail address*: isabel.bagudanch@udg.edu

Selection and peer-review under responsibility of Universidad de Zaragoza, Dpto Ing Diseño y Fabricacion
doi:10.1016/j.proeng.2013.08.208

Nevertheless some attempts have been carried out and presented as in scientific journals (Ingarao et al., 2011) as in the last and main forming conferences (Duflou et al., 2011; Anghinelli et al., 2011). Duflou et al. (2011) described results of two case studies performed at the Belgian Katholieke University of Leuven on air bending and laser cutting processes. Ingarao et al. (2011) and Anghinelli et al. (2011) have given Italian contributions, establishing references on sustainability issues for metal forming processes and bringing environmental cost in Incremental Sheet Forming (ISF), respectively.

In order to be able to produce highly customized products with a reasonable manufacturing cost, several innovative forming processes have been developed. Incremental Sheet Forming (ISF) is one of these new technologies and it has gained importance in the last years, becoming the focus of interest for many researchers and institutions (Martins et al., 2008; Attanasio et al., 2009; Jeswiet et al., 2005; Centeno et al., 2012; Bagudanch et al., 2011).

The ISF process can be conducted in any numerically controlled 3-axis machine as they allow high feed rates, significant work volume and stiffness. Indeed, one of the most frequent resources used for ISF is a CNC milling machine because it is available in most workshops, meaning that it is not necessary to make a large investment in machinery. Besides the forming tool, a clamping system is required to convert a milling machine into an ISF system, therefore is a relatively economic solution.

The framework defined by the previous works on environmental issues and the ISF background that the authors have been creating in the last years have been the trigger of the work developed in this paper. Thus, the energy consumption of a CNC machine when it works as Single Point Incremental Forming (SPIF) configuration (Fig. 1) has been studied experimentally. The calculation of CO_2 emissions for the ISF-formed part has been also carried out under the Spanish framework.

2. Experimental procedure: materials and methods

The experimental equipment used in this work is made up of 3 main elements: i) a Kondia HS1000 3-axis milling machine, ii) a SPIF fixture system (a bottom plate, four supports, a clamping plate and a top plate), iii) a forming hemispherical steel tool of 10 mm diameter, Fig. 1.

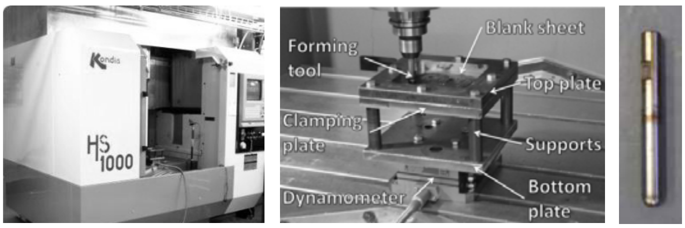

Fig. 1. Experimental equipment.

According literature review, electric energy consumption of the ISF machine is very important because is directly related to the final cost of the formed part besides environmental concerning. Thus, the electrical consumption of the milling machine per part will be evaluated experimentally. The required means to carry this measurement out is an ammeter clamp (LIMIT 21) on the CNC-ISF electric supply cable. The range of measures available is from 2 to 400A. Maximum and mean intensity consumed during the period of measure were saved.

Previously to the design of experiments definition and with the purpose of reducing design of experiments matrix, a reduced set of preliminary tests were done in order to assess which parameters under forming conditions produced a variation in electric consumption. Once the influenced parameters were established, the design of experiments was defined. Mean intensity and deforming time are recorded and used to obtain consumed power and energy. CO_2 emissions will be estimated using machine consumptions and estimating raw material consumption from Anghinelli et al. (2011).

2.1. Preliminary tests, parameters influencing energy consumption

Five different experiments were performed in this research. In each one of them only a parameter was varied (Table 1 and Fig. 2) and the two values corresponding to maximum and mean intensity consumed were controlled to asses if there were influencing on energy consumption.

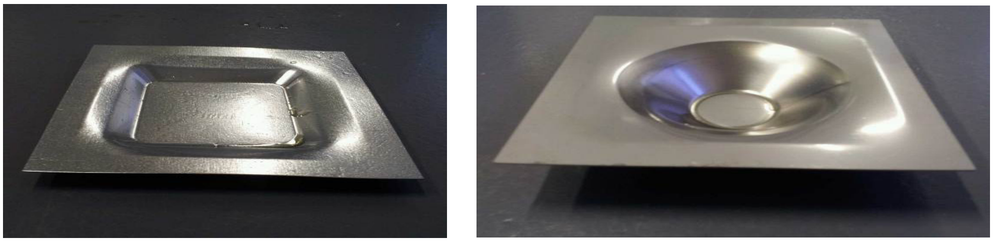

Fig. 2. Pre-test geometries (same depth, 40mm): (left) pyramid 100 x 100mm, right (Dinit 100 mm)

2.2. Design of Experiments

Preliminary tests results allow detecting which parameters vary energy consumption. From them, design of experiments matrix definition will be more focused to detect which are the better conditions to form by ISF under minimum consumption conditions.

Table 1. Preliminary tests.

Parameter	**Experiments**					**Consump. Variation**
	#1	#2	#3	#4	#5	
Sheet	**0,8 mm AISI304 / 0,5 mm AA1050H24**	0,5 mm Z20				Yes
Geometry	Cone	**Cone / Pyramid**	Cone			No
Incremental step	0,2 mm		**0,2 /0,5 mm**	0,2 mm		Yes
Spindle speed	2000rpm			**Free / 2000rpm**	2000rpm	Yes
Feed rate	3000 mm/min				**1500 /3000 mm/min**	**No**

Geometry (pyramid) and the feed rate were set as constants, and the variable parameters were defined as follows: 3 sheet materials with 2 thicknesses, 2 depth steps and 2 spindle speeds. A total of 24 experiments were carried out, Table 2. Aluminum plates requires based bituminous grease as lubricant, and steel sheets, lubricating fluid type Houghton TD-52, which is specific for cold deformation processes.

2.3. Energy consumption

Previous energy consumption calculation, power consumption is estimated with the recorded values of mean intensity, by means of Equation 1.

$$P = \sqrt{3} \times I \times V \times \cos\varphi \tag{1}$$

Where P (W) is the power consumption, I (A) is the intensity, V (V) is the machine's voltage, in this case 380V, and, cosφ is the phase difference between the intensities of the line respect to the equilibrated tensions, in this case 0,9. Next, energy consumption can be obtained from Equation 2.

$$E = P \times t \tag{2}$$

Where E (J) in energy consumption and t(s) is the time in which is consumed.

2.4. CO_2 emissions

In the current context, where it is increasingly important to protect the environment, CES (Carbon Emission Signature) indicator has emerged in order to measure the amount of CO_2 emissions that arise when any energy or material is produced. Therefore you can estimate which material production or manufacturing process, or energy generation is more beneficial for the environment (Anghinelli et al., 2011).

The equation to CES calculation is as follows:

$$CES = (1/\eta) \times (112K_c + 49K_{NG} + 66K_P \tag{3}$$

Where η is an efficiency coefficient, it is different for each country and (1/ η) is usually between 0,25 and 0,35, for Spain 0,34 (Anghinelli et al., 2011). The K_C, K_{NG} and K_P, are, respectively, the percentages of coal, oil and natural gas used to produce energy in a particular country or by a supplying electricity company.

CO_2 emissions for manufacturing an ISF pyramid 100 x 100mm (Fig. 2, left) in our shop floor with a CNC mill Kondia HS1000 will be measured, taking into account the consumptions of the machine and the estimated consumptions for raw material obtaining.

$$CO_2 = CO_{2\,electricalconsumption} + CO_{2\,rawmaterialmanuf} \tag{4}$$

CO_2 emissions due to electrical consumption depend on electric consumption supplier (ENDESA ENERGIA, S.A., in our case). Determining the energy mix which supplier has provided to their customers with has been done. With these values (18,0% C, 2,9% for N, 20,3% for P) and Equation 3, CES value of the shop floor energy consumption is estimated, 10,89 kg CO_2/GJ. This factor will be applied to energy consumption in order to obtain CO_2 emission due to electrical consumption.

For raw material estimation consumption, two origin hypotheses will be considered for each material: mineral or recycled, Table 2. From these data and because volume is also known, energy consumption can be found.

Table 2. Consumption of energy according material manufacturing (GJ/m^3) (Anghinelli et al., 2011).

Aluminum from Bauxite	**Recycled Aluminum**	**Copper**	**Recycled Copper**	**Mineral Steel**	**Recycled Steel**
810	115	942	497	429	76.4

According the previous values, then, the global value of 21,2kg CO_2/GJ is applied and CO_2 for raw material manufacturing found. This global value from Anghinelli et al. (2011) is used since materials are manufactured around the world and each local supplier is not always buying to the same manufacturer.

3. Results and discussion

The results according to the variable parameters are shown from Fig. 3 to Fig. 6. From material variation influence (Fig. 3), as it could be expected, the more malleable the sheet is, the less energy is consumed as can be observed in 1050 H24 aluminum sheets, followed by galvanized Z20 steel and AISI 304 sheet. It must be said that in two measurements this trend cannot be observed, probably due to two errors in the measurement process.

Thickness influence on energy consumption is mainly noticed in the experiments in which the tool has spindle speed, but it looks that thickness variation does not have a strong impact (Fig. 4). This effect will be checked by means of an ANOVA analysis.

Table 3. Design of experiments matrix and results.

Id	Material	Thickness (mm)	Incremental Step (mm)	Spindle Speed (rpm)	Mean Intensity (A)	Time (s)	Energy Cons. (kJ)	CO_2 emis. (g) Mineral	Recycled
1	1050 H24	0,5	0,2	Free	3,65	302	653,96	194,12	34,12
2		0,5	0,2	2000	6,05	419	1.501,61	203,35	43,35
3		0,5	0,5	Free	3,67	230	500,01	192,44	32,44
4		0,5	0,5	2000	5,48	351	1.139,39	199,40	39,40
5		0,8	0,2	Free	3,66	301	652,58	313,10	51,10
6		0,8	0,2	2000	6,31	423	1.581,09	323,21	61,21
7		0,8	0,5	Free	3,65	231	499,45	311,43	49,43
8		0,8	0,5	2000	5,98	363	1.285,86	320,00	58,00
9	Z20	0,5	0,2	Free	3,74	298	660,20	108,18	25,18
10		0,5	0,2	2000	6,20	421	1.546,18	117,83	34,83
11		0,5	0,5	Free	3,77	237	529,27	106,76	23,76
12		0,5	0,5	2000	6,03	234	835,83	110,10	27,10
13		0,8	0,2	Free	3,77	299	667,73	173,27	37,27
14		0,8	0,2	2000	6,18	424	1.094,58	177,91	41,91
15		0,8	0,5	Free	3,79	236	529,83	171,76	35,76
16		0,8	0,5	2000	6,13	361	1.310,85	180,27	44,27
17	AISI 304	0,5	0,2	Free	3,79	299	671,27	108,31	25,31
18		0,5	0,2	2000	6,19	424	1.554,69	117,93	34,93
19		0,5	0,5	Free	3,81	361	814,74	109,87	26,87
20		0,5	0,5	2000	6,16	356	1.299,02	115,14	32,14
21		0,8	0,2	Free	3,80	301	677,54	173,37	37,37
22		0,8	0,2	2000	6,34	422	1.584,85	183,25	47,25
23		0,8	0,5	Free	3,81	234	528,11	171,75	35,75
24		0,8	0,5	2000	6,29	361	1.345,07	180,64	44,64

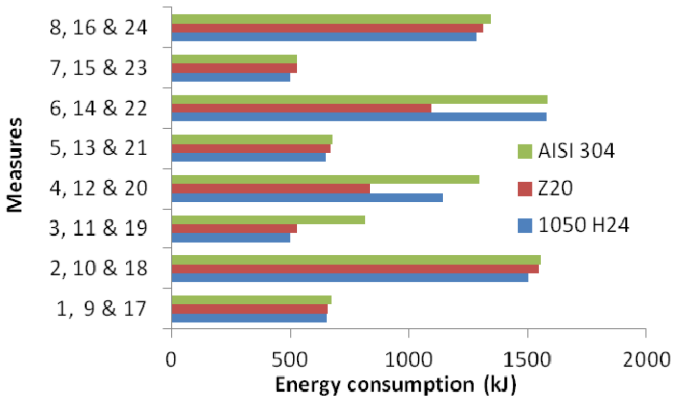

Fig. 3. Energy consumption according to material variation.

Incremental step affects the consumption, (Fig. 5). When the incremental step 0,2 mm was used, the consumption was higher compared with that of incremental step of 0,5 mm. Thus, higher incremental steps involve less energy consumption. It should be noted that both incremental steps share the same inclination angle and the tool does the same number of laps. That means that the diameter of the piece at last layers is lower for an incremental step of 0,5 mm and therefore, if the feed rate is constant, the manufacturing time is also lower, which affects energy consumption.

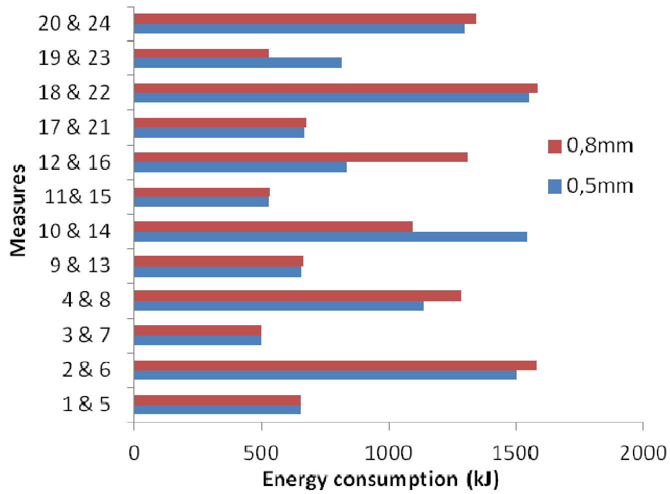

Fig. 4. Energy consumption according to thickness variation.

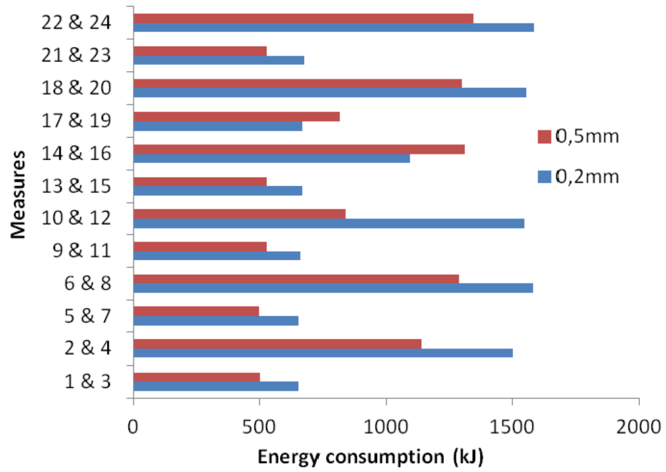

Fig. 5. Energy consumption according to incremental step variation.

Finally, spindle speed influence is the strongest among the others, (Fig. 6). Free rotation consumes about 50% less than when the tool spins at 2000rpm. The reason is because when the spindle speed is lower, the friction between the sheet and the tool is smaller and, therefore, the deformation process can be carried out more easily. Moreover, production time is significantly reduced if the rotation of the tool is free, because when the head rotates, each time the tool has to descend the incremental step, rotation must be stopped, and return when it has gone down.

ANOVA analysis was carried out and as the previous analysis indicated, spindle speed is the most significant parameter, whereas incremental step and material also affects the consumption. The influence of the thickness can be negligible (Fig. 7).

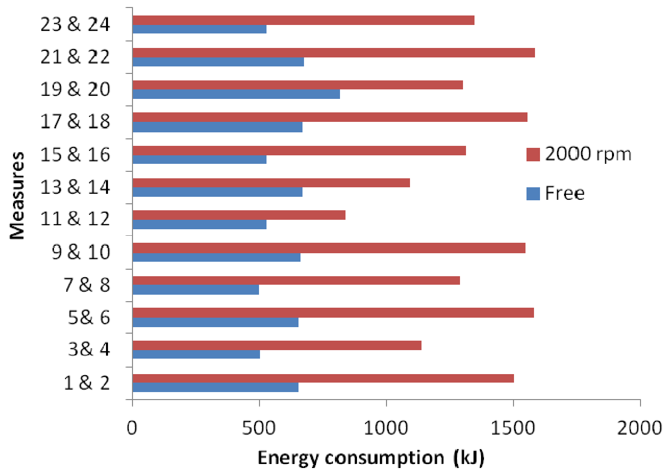

Fig. 6. Energy consumption according to spindle speed variation.

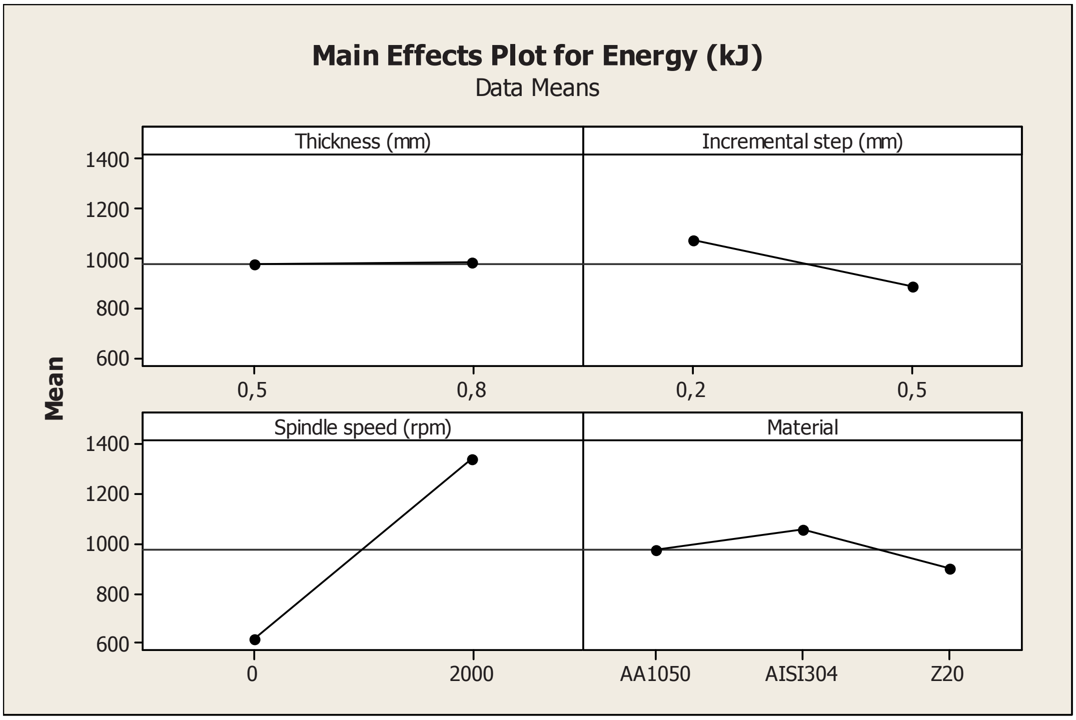

Fig. 7. Parameters influence on electric energy consumption.

4. Conclusions

In the present paper, the influence of ISF process parameters on energy consumption has been determined. Feed rate and geometry type have no significant influence on electricity consumption, while spindle speed, type of material, thickness and incremental step do. These influence effects on consumption will be taken into account in future researches, because it can determine the selection of parameters under minimum consumptions and also reduce pollution contribution. Finally, CO_2 emissions analysis has identified the importance of the origin of raw material on CO_2 total emissions and the effect of recycling, which can raise sustainability awareness.

Acknowledgements

The research leading to these results has received funding from the Spanish government, DPI2009-09852.

References

Anghinelli, O. et al. 2011. Enviromental Costs of Single Point Incremental Forming. Steel Research Int., pp. 525–530.

Attanasio, A. et al. 2009. Experimental test to study feasibility and formability in incremental forming process. Key Engineering Materials, 410-411, pp. 391-400.

Bagudanch, I. et al. 2011. Tool path stratagies for single point incremental forming. Key Engineering Materials 473, pp. 905-912.

Centeno, G. et al. 2012. FEA of the Bending Effect in the Formability of Metal Sheets via Incremental Forming, Steel Research International, Special Edition: 14th Metal Forming International Conference, 447-450.

Duflou, J.R. et al. 2011. Environmental Performance of Sheet Metal Working Processes. Key Engineering Materials, 473, pp. 21–26.

Ingarao, G. et al. 2011. Sustainability issues in sheet metal forming processes: an overview. Journal of Cleaner Production, 19(4), pp. 337–347.

Jeswiet, J. et al. 2005. Asymmetric single point incremental forming of sheet metal. CIRP Annals - Manufacturing Technology, 54(2), pp. 88-114.

Martins, P.A.F. et al. 2008. Theory of single point incremental forming. CIRP Annals - Manufacturing Technology, 57(1), pp. 247-252