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Improve the Micro-hardness of Single Point Incremental Forming Product Using Magnetic Abrasive Finishing

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K E Y W O R D S

SPIF, MAF, Micro-Vickers hardness, Box-Behnken design.

A B S T R A C T

In this paper the Magnetic Abrasive Finishing (MAF) was utilized after Single Point Incremental Forming (SPIF) process as a combined finishing process. Firstly, the Single Point Incremental forming was form the truncated cone made from low carbon steel (1008-AISI) based on Z-level tool path then the magnetic abrasive finishing process was applied on the surface of the formed product. Box-Behnken design of experiment in Minitab 17 software was used in this study. The influences of different parameters (feed rate, machining step size, coil current and spindle speed) on change in Micro-Vickers hardness were studied. The maximum and minimum change in Micro-Vickers hardness that achieved from all the experiments were (40.4 and 1.1) respectively. The contribution percent of (feed rate, machining step size, coil current and spindle speed) were (7.1, 18.068, 17.376 and 37.894) % respectively. After MAF process all the micro surface cracks that generated on the workpiece surface was completely removed from the surface.

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1. Introduction

Single point incremental forming (SPIF) is a sheet metal forming process for rapid prototyping applications and small quantity production. The basic components of SPIF are (blank of sheet metal, blank holder, backing plate and forming tool). The SPIF tool is used to progressively shape the sheet into a component and its path is generated by a CNC machine [1]. In new manufacturing techniques, it is required the final surface created after many manufacturing activities should have good finish and surface properties. Components produced after manufacturing operations does not have needed surface finish and surface properties in the utmost of cases. So, different methods adapted to getting the required surface finish and properties. When vary near control of surface finish and properties are desired, a modern finishing process named Magnetic Abrasive Finishing (MAF) has been developed for this purpose [2]. One of the nonconventional super finishing processes is the Magnetic abrasive finishing (MAF) which has many different finishing applications for example finishing of screws, bearings parts, flat plates, tubes and mechanical parts that need a good surface finishing characteristics. MAF is also used for polishing, cleaning, deburring and burnishing of metal parts with high efficiency [3]. V. Gulati et al. (2015) optimized the formability and surface roughness of parts (Aluminium-6063) formed by the SPIF process. Radius of tool, thickness of sheet, step size, rotational speed of tool, feed rate and lubrication type are the parameters were studied. The responses of the process are surface roughness and wall angle of product. The results show that the lubrication is the parameter that has the utmost influence on formability and surface roughness [4]. Xie et al. [5] investigated the magnetic abrasive finishing mechanism by utilizing alternating magnetic field. The effect of magnetic abrasive mesh size and the frequency of magnetic field on change of magnetic cluster were studied and analyzed the relationship between alternating magnetic field and finishing force. From the results obtained the surface roughness of 5052 aluminum alloy was enhanced from (318 to 3) nm during 15 min. Sharif Uddin et al. [6] investigated the basic interaction between process parameters of MAF in improving quality of work piece surface. Two types of abrasive powder were used (Sic and Al2O3) with five parameters (working gap, rotational speed, feed rate, abrasive amount, and abrasive mesh). Results show that the rotational speed and quantity of abrasive powder have significant effect when using Sic powder. On the other hand, the mesh size of abrasive and the working gap are dominant during Al_2O_3 powder. In the presented work for the first time as a modern finishing process Magnetic Abrasive Finishing (MAF) was applied after Single Point Incremental Forming (SPIF) process as a combined process at the same setup of work piece. The aim of this work is to enhance the surface hardness of SPIF of truncated cone made from low carbon steel work piece (1008-AISI).

2. Experimental Procedure

Incremental Sheet Metal Forming (ISMF) is performed on CNC milling machine, where it is possible to control and assign the movement of tool according to the desired paths. The forming frame that used in the experimental work is shown in Figure 1. Firstly, hemispherical head of the cylindrical tool manufactured from tool steel with diameter (12 mm) is utilized in order to form the required shape after forming the truncated cone then the MAF tool as a second finishing process has been used to finish the required shape. The MAF tool is electromagnetic spherical tool with diameter of (20 mm) that illustrated in the Figure 2. It consists of iron core covered with copper wire with number of turns equal to 4500 turn to produce high electromagnetic field. The Samples of low carbon steel (1008-AISI) sheets with dimensions (250x 250 x 0.5) mm, were used to perform the 27 experiments. The experimental work during SPIF was applied using oil lubricant SAE 30 on RAPIMILL 700 CNC milling machine. The chemical composition of work piece illustrated in Table 1. The magnetic abrasive powder is prepared by mixing pure iron powder with tungsten carbide powder by 50 percent of each of them with sintering method at temperature of 350°C then ball mill and sieving machines were used to get the magnetic abrasive powder with 300 µm mesh size. The dimension of the truncated cone is illustrated in Figure 3. The magnetic abrasive powder amount was 5 grams with 1.5 machining gap during MAF process.

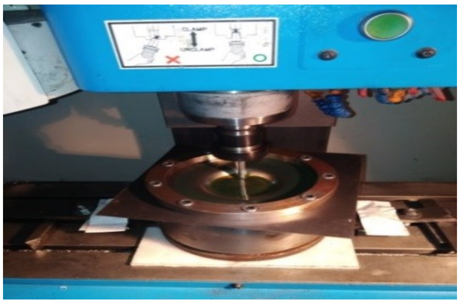


Figure 1: The forming frame being used for experiments

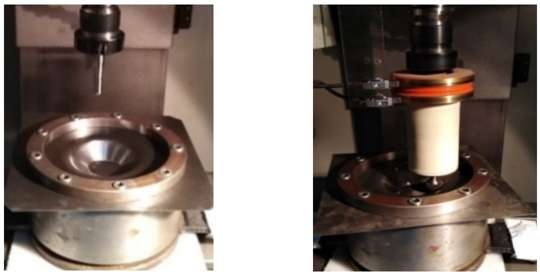


Figure 2: A: SPIF tool and B: MAF tool

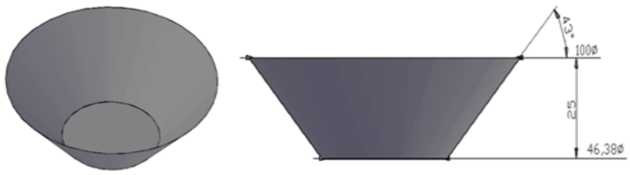


Figure 3: Dimension of performed truncated cone

2. Plan of Experiments

Box-Behnken design method has become during research and development in recent years so at low cost that can be produced good quality parts quickly. Uses a special design of orthogonal arrays with a small number of experiments Box-Behnken method to study the entire parameter space. The Box-Behnken design was used for response micro- hardness methodology due to it permits: (i) detection of lack of fit of the model; (ii) estimation of the parameters of the quadratic model; and (iii) building of sequential designs. The methodology of Box-Behnken for four factors at three levels is used for applied of experiments. The levels and process parameters are illustrated in Table 2. Table 3 illustrates the present work and the test results. The hardness measured in 27 specimens, after SPIF and after the MAF process, the differences in HV values (before and after MAF process) at three different locations and then the values were averaged by using Micro hardness tester.
Micro- Vickers hardness (HV) for MAF specimens is computed as follows:

$\Delta Hv = Hv \text{ after MAF} - Hv \text{ before MAF}$

Table 1: Chemical composition of work piece (1008-AISI)

Alloying element%	C	Si	Mn	S	P	Cr	Ni	Mo	V	Cu	Al	Fe
Experimental	0.08	0.02	0.32	0.024	0.014	0.035	0.032	0.002	0.001	0.072	0.044	Remain

Table 2: MAF parameters and their levels.

Parameters	Unit	Level 1	Level 2	Level 3
Rotational Speed (S)	Rev/min	420	580	740
Feed Rate (F)	mm/min	30	40	50
Machining step size (ΔZ)	mm	3	3.5	4
Coil current (I)	ampere	1.7	2.2	2.7

The Machining step size (ΔZ) is meaning that the step size per revolution of the Z-level tool path being used in this experimental investigation. Lower values of (ΔZ) meaning higher machining time and cost while higher values meaning worst surface of product.

Table 3: Experimental layout using Box-Behnken design and corresponding results.

Exp. No.	Spindle speed (S)rev/min	Feed rate (F)mm/min	Machining step size (ΔZ)mm	Coil current (I)ampere	Change in micro hardness (ΔHV)
1	580	30	3.0	2.2	15.6
2	580	50	3.0	2.2	23.8
3	580	30	4.0	2.2	25.7
4	580	50	4.0	2.2	31.8
5	420	40	3.5	1.7	10.4
6	420	40	3.5	2.7	28.1
7	740	40	3.5	1.7	1.4
8	740	40	3.5	2.7	1.1
9	420	30	3.5	2.2	9.2
10	420	50	3.5	2.2	17.6
11	740	30	3.5	2.2	2.1
12	740	50	3.5	2.2	2.1
13	580	40	3.0	1.7	4.9
14	580	40	4.0	1.7	23.9
15	580	40	3.0	2.7	29.6
16	580	40	4.0	2.7	19.6
17	580	30	3.5	1.7	6.2
18	580	50	3.5	1.7	11.1
19	580	30	3.5	2.7	13.6
20	580	50	3.5	2.7	21.7
21	420	40	3.0	2.2	7.4
22	420	40	4.0	2.2	40.4
23	740	40	3.0	2.2	13.6
24	740	40	4.0	2.2	10.4
25	580	40	3.5	2.2	4.8
26	580	40	3.5	2.2	4.5
27	580	40	3.5	2.2	4.7

3. Results and Discussion

The main effect plot of change in Micro hardness is illustrated in Figure 4. The magnetic force lines generated power to apply pressure from the magnetic abrasives to the work piece [7]. If P is the magnetic pressure acting on a spherical abrasive grain of diameter d; the normal force F_n acting on it is given by Jain et al. [8].

$$F_n = \frac{P\Pi d^2}{4} \quad (1)$$

$$h_d = \frac{d}{2} - \sqrt{\frac{d^2}{4} - \left(\frac{F_n}{H_W \Pi}\right)} \quad (2)$$

In the working gap the concentrating of magnetic abrasive particles is the responsibility of normal magnetic force which causes micro indentations in the work piece surface [9].
The hardness of work piece material is given by the following equation [8]:
Where:
hd = abrasive indentation depth.
Hw = workpiece material hardness.
d = abrasive grain diameter.
From Eq. (1) and Eq. (2) the work surface hardening action causes increase in work piece hardness when the normal magnetic force increases which caused by increasing of magnetic pressure. When rotational speed increases decreasing in normal magnetic force occur which causes decreasing in surface hardness improvement. Splashing of magnetic abrasives from the machining gap at high speed may be happen when normal magnetic force reduces. From Figure 4 it seen that when the coil current increase the change in Micro-Vickers hardness also increases. While higher number of indentations in the work piece surface occur when the coil current increase due to increasing in strength of the magnetic brush [9]. Hence, normal magnetic force raises leading to rise in hardness

Eq. (2). Little effect of feed rate on change in Micro-Vickers hardness is shown in Figure 4, when the feed rate increases from (30 to 50) mm/min the improvement of change in Micro-Vickers hardness occurs. The influence of machining step size on change in Micro-Vickers hardness is showing in main effect plot (Figure 4), firstly the ΔHV decreases when increasing ΔZ from (3 to 3.5) mm then increasing the change in Micro-Vickers hardness with increasing ΔZ from (3.5 to 4) mm. From using the Minitab 17 software the contribution percent of machining parameters (F, ΔZ, I and S) were (7.1, 18.068, 17.376 and 37.894) % respectively. Where the S was the greatest influencing parameter on change in Micro-Vickers hardness. The surface plot of change in micro hardness is shown in Figure 5. The obtained regression equation of change in Micro hardness (ΔHV) is:

$$\Delta HV = 196 - 2.73 F - 221.8 \Delta Z + 72.9 I + 0.522 S + 0.0476 F2 + 52.13 \Delta Z2 + 14.58 I2 + 0.000007 S2 - 0.105 F\times\Delta Z + 0.160 F\times I - 0.00131 F\times S - 29.00 \Delta Z\times I - 0.1131 \Delta Z\times S - 0.0563 I\times S$$

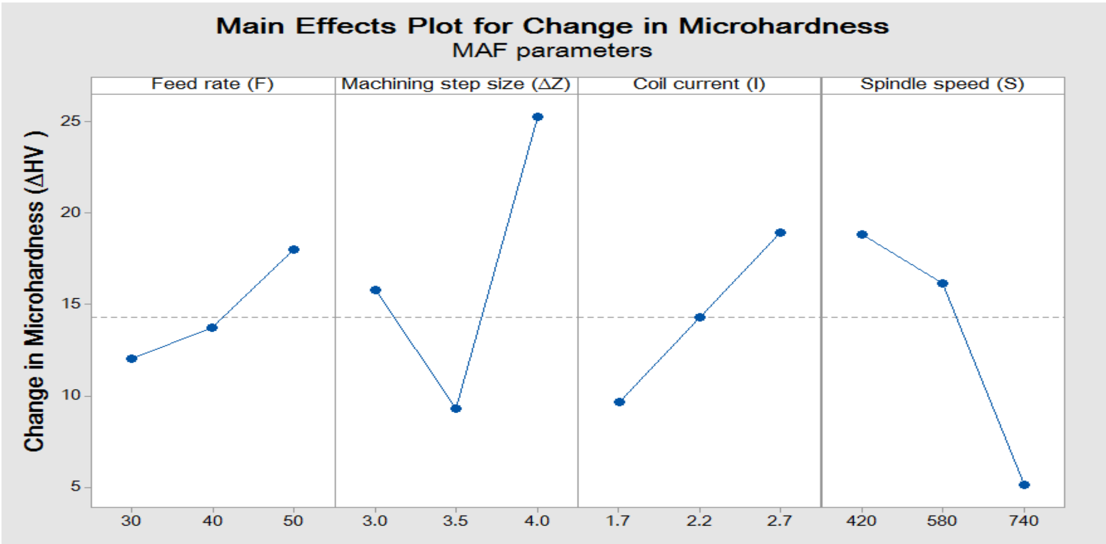


Figure 4: Main effect plot for change in Micro hardness

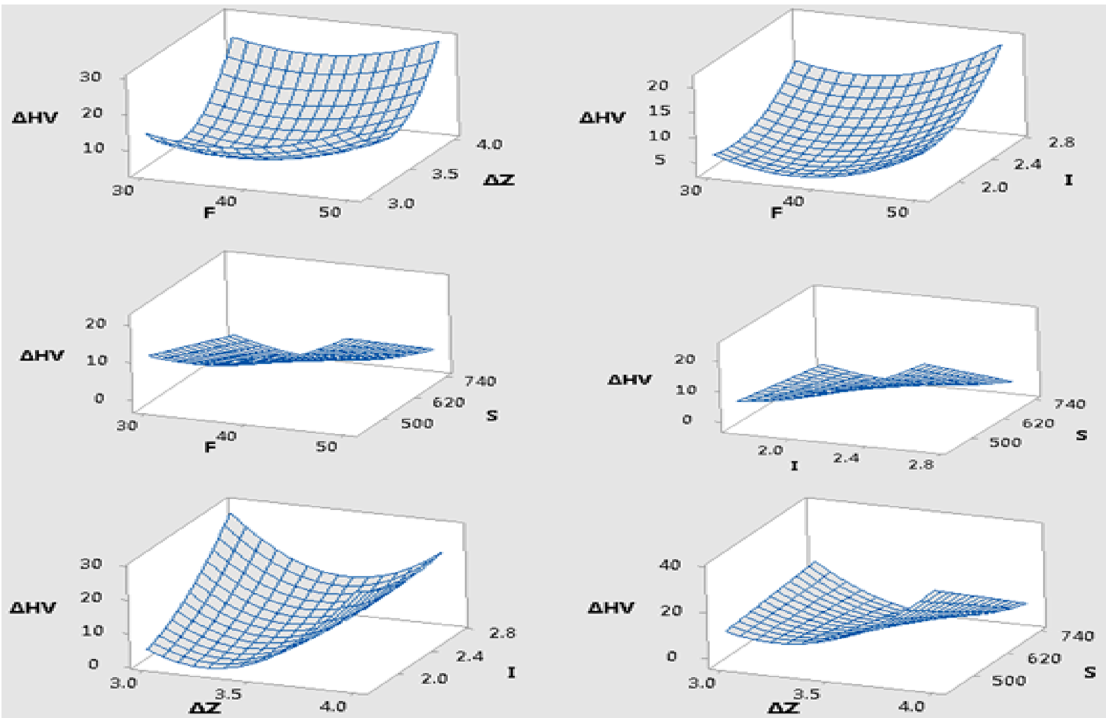
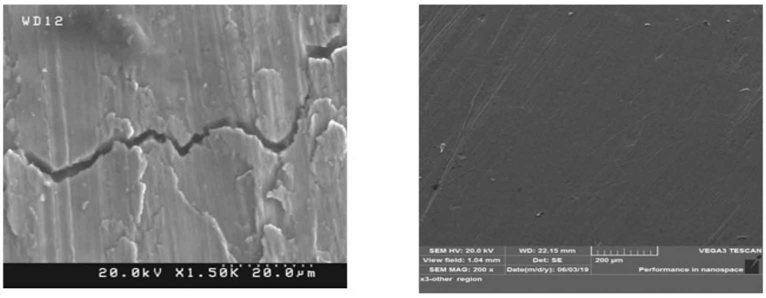


Figure 5: Surface plots of change in Micro hardness

After MAF process all the micro surface cracks that generated on the work piece surface by SPIF process is completely removed from the surface. Were the work piece surface is tested by using scanning electron microscope (SEM) as illustrated in Figure 6.



A B

Figure 6: SEM of SPIF (A) and SEM of MAF (B).

4. Conclusions

The conclusions of this study can be listed to the major points:

1. There is a high feasibility of applying the magnetic abrasive finishing process (MAF) to the surface being formed by single point incremental forming process (SPIF) as a finishing process to enhance the surface micro hardness.
2. From the effects of different parameters (feed rate, machining step size, coil current and spindle speed) during MAF process on (1008-AISI) work piece the spindle speed was the great significant on change in Micro-Vickers hardness.
3. The contribution percent of machining parameters (F, ΔZ, I and S) were (7.1, 18.068, 17.376 and 37.894) % respectively. The S was the greatest influencing parameter
4. The maximum and minimum change in Micro-Vickers hardness that achieved from all the 27 experiments are (40.4 and 1.1) respectively.
5. All the micro surface cracks that generated on the work piece surface by SPIF process is completely removed from the surface after applying MAF process.

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