Nano World Journal

https://doi.org/10.17756/nwj.2023-s4-061

Research Article

Open Access

Experimental Investigation on Single Point Incremental Forming Process Using Conventional Fluid and Solid Lubrication

Chakradhar Bandapalli[1], Balasubramaniyan Singaravel[1*] and Thiruchinapalli Niranjan[2]

[1]*Department of Mechanical Engineering, Vignan Institute of Technology and Science, Hyderabad, Telangana, India*

[2]*Department of Mechanical Engineering, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India*

[*]Correspondence to:
Balasubramaniyan Singaravel
Department of Mechanical Engineering,
Vignan Institute of Technology and Science,
Hyderabad, Telangana, India.
E-mail: singnitt@gmail.com

Received: September 15, 2023
Accepted: November 27, 2023
Published: November 30, 2023

Citation: Bandapalli C, Singaravel B, Niranjan T. 2023. Experimental Investigation on Single Point Incremental Forming Process Using Conventional Fluid and Solid Lubrication. *NanoWorld J* 9(S4): S356-S360.

Published by United Scientific Group

Abstract

Single Point Incremental Forming (SPIF) is one of the forming processes that have higher formability which is the significant advantage when compared to other type of forming processes. Cutting conditions play a significant role in process performance enhancement. Cutting conditions include conventional fluid, dry condition, coated tool, vegetable oil as coolant, minimum quantity supply, and nano solid lubricant. In this work, two different cutting conditions are considered, and the process performance is analyzed. Conventional cutting fluid and nano powder mixed solid lubrication are considered as cutting conditions. Forming tool diameter, speed of the spindle, and step size are considered as process parameters. Response parameters such as surface roughness, machining time, vibration of tool, and temperature are measured. The result revealed that nano powder mixed solid lubrication is performed better and one of the easiest alternative cutting conditions. Nano powder mixed cutting fluid is used to enhance the tribological properties by reducing the frictional effect during machining. This research work promotes near dry machining effectively with the help of nano powder mixed solid lubrication.

Keywords

Single point incremental forming, AA-6082, Process performance, Cutting conditions, Nano solid lubrication

Introduction

Metal forming process is a kind of manufacturing process which is attractive due to less material waste, very high close tolerance, and high efficiency. SPIF is a type of metal forming process which involves die less for performing shapes. In SPIF process, the forming tool moves inside and steps down gradually. SPIF process has significant advantages like higher formability when compared to deep drawing process; hence it is highly recommended for small batch type of production and asymmetric shape fabrication [1, 2].

During SPIF process, friction exists between the tool and workpiece. Generally, it can be reduced with the help of cutting fluid. It is used to reduce the frictional co-efficient and enhance the formability. But, in general hydrocarbon oil-based cutting fluid is used in manufacturing industries. This type of cutting fluid is harmful to the environment and causes soil and ground water level contamination and operator health issues. To avoid these issues, researchers attempted alternative cutting conditions. Solid lubrication can be considered for alternative cutting conditions which involve solid lubricant paste are applied during the machining process. Nanoparticle mixed cutting fluids are easy to spread, absorb, squeeze, and leads to better lubrication film. This will be useful for effective cooling and enhancement of machining. This film layer is used to reduce the frictional heat and enhance the tribological conditions [3-5].

A performance study using solid lubrication was conducted [6]. In their study, three types of solid lubrication were used. The result revealed that tribological properties of formed components were enhanced using solid lubricants. SPIF process and investigation about surface quality and formability was done [7]. In their work, different types of cutting conditions like dry condition, solid lubrication (Molybdenum disulfide) and air were used. The result revealed that solid lubrication contributed better performance.

Pavani et al. [8] investigated the performance of vegetable oil as cutting fluid when mixed with nano boric acid. The results of the experiments were compared with other cutting conditions, namely dry and wet conditions. Machining performance was improved with nano powder mixed cutting fluid. Singh et al. [9] used hybrid nanofluid as cutting fluid in machining. Alumina and graphene nanoparticles were mixed with different volume concentration. The result of the experiment was observed that tribological and thermal properties were enhanced through nanofluid. Öndin et al. [10] performed a machinability study on corrosion resistance steel using nano powder mixed cutting fluid. Thermal conductivity of the cutting fluid was enhanced using nano powder addition. The result revealed that reduction of surface roughness and machining force effectively. Padmini et al. [11] investigasted nanoparticle mixed cutting fluid in machining. Vegetable oil was selected as base oil and the result revealed that machinability characteristics were enhanced with the addition of nanoparticles.

From the literature review, few researchers have attempted different alternative cutting conditions. They noticed environmental issues and operator health issues with hydrocarbon oil-based cutting fluid. Nano solid lubrication is a better alternative to get reduced frictional effect during forming process. In this work, performance comparison is made on nano powder mixed solid lubrication and conventional coolant conditions.

Experimentation

AA-6082 sheets are utilized as workpiece materials that have wide application in building of ship, architectural, and structural applications. Fixture is used for performing SPIF process. Sheet dimensions are 150 mm x 150 mm x 1 mm. High speed steel with hemispherical shape is used as tool material. Two different cutting conditions are carried out in this experimentation. First conventional cutting fluid, then second nano powder (Al_2O_3) mixed tungsten disulfide is utilized as solid lubrication. Alumina is selected as nano powder and mixed to base solid lubricant with 1% weight concentration. Past literature and trial experiments are used for selecting the weight concentration of nanoparticles. Figure 1 shows the workpiece, tool, and fixture. SPIF process is carried out using Vertical Machining Center (VMC). Figure 2 represents the VMC setup used for SPIF process. Tool rotational speed, step size, and tool diameter are the input process parameters as shown in table 1. Surface roughness is the output parameter. Taguchi L_9 orthogonal matrix is used to execute the forming process. The formed components are forming figure 3. Surface roughness testing was done on the formed surface using Talysurf testing machine as shown in figure 4a. Infrared thermal imaging camera as shown in figure 4b is used for measurement of temperature during the process. Forming time is noted using stopwatch during the process. Experimental results attained are shown in table 2.

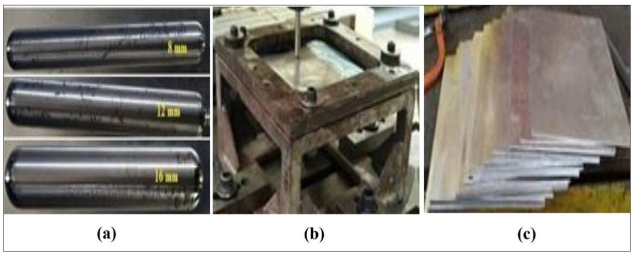

Figure 1: (a) Tool, **(b)** fixture, and **(c)** worksheet in SPIF.

Figure 2: VMC instrument.

Table 1: Process parameters and their levels.

S. No.	Parameters	Unit	Level 1	Level 2	Level 3
1	Tool diameter	mm	8	12	16
2	Tool rotational speed	rpm	700	1100	1500
3	Step size	mm	0.2	0.4	0.6

Results and Discussion

SPIF process is attractive due to less die to form a shape. In SPIF process, localized working zone of sheet metal get compressed and sheared continuously. It is highly suitable for low costs as well as small batch production. In this work, machinability investigation is carried out using conventional cutting fluid and solid lubrication. Process parameters like spindle speed, diameter of forming tool, and step size are used. The considered response parameters are surface quality, vibra-

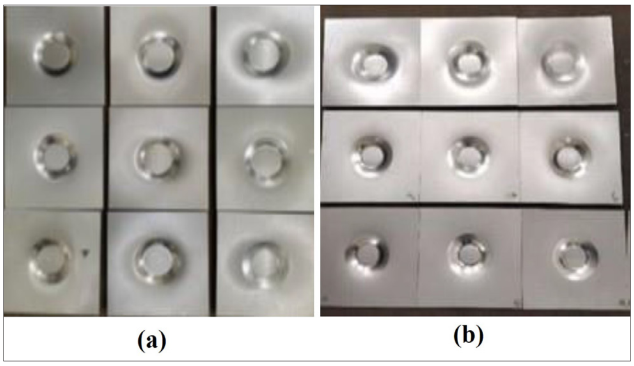

Figure 3: Formed components: **(a)** Conventional fluid and **(b)** Solid lubrication.

Figure 4: Measuring devices: **(a)** Surface roughness tester and **(b)** Infrared thermal imaging.

tion during the process, and forming time. The variation of response parameters is shown in figure 5.

Effects of nano powder mixed solid lubrication

In SPIF process, surface friction is involved in between tool and sheet. This friction leads to degradation of forming tool, heat-affected zone on sheet and surface roughness. Lubrication is required to minimize the surface friction during SPIF. Solid lubrication effectively acts as alternative cutting conditions. Generally, it is a solid form which generates thin lubrication film due to frictional heat during tool-workpiece interaction takes place followed by heat generation. This is called thermal expansion of solid lubricant. In this investigation, tungsten disulfide is considered as solid lubricant. It has properties like lower shear strength, hexagonal layered structure, thin and brittle in nature and low friction of co-efficient-due to these it is easily smeared and forming a thin layerduring

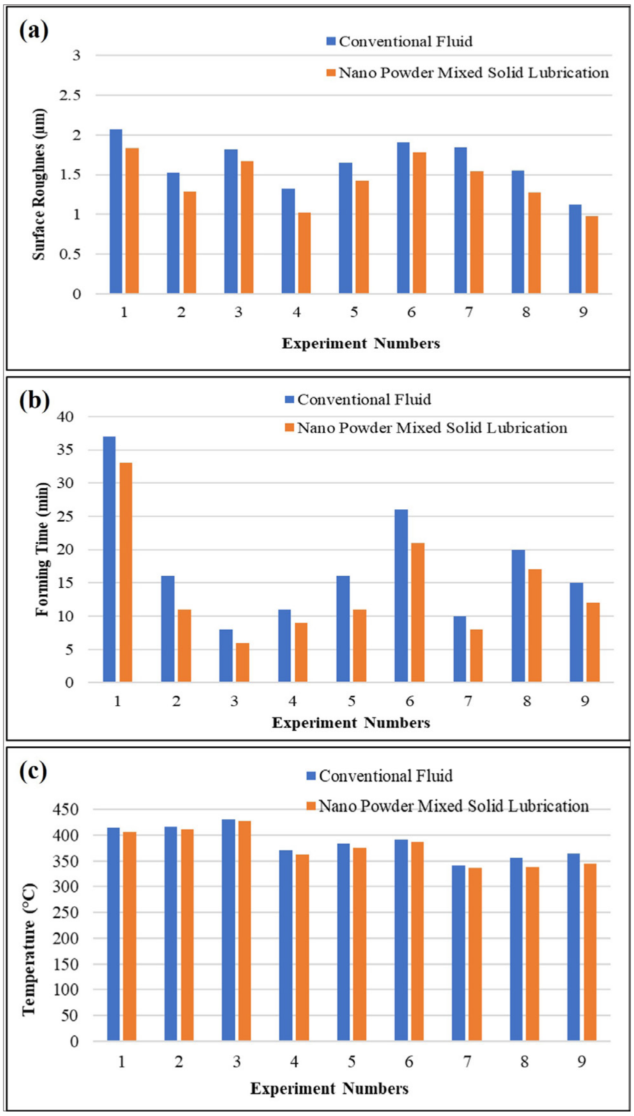

Figure 5: Variation in **(a)** surface roughness, **(b)** forming time, and **(c)** forming temperature.

the process takes place [11, 12]. Hence, better surface quality is observed with better lubricity and anti-adhesion effect. Few issues with solid lubrication are also noticed appropriate quantity, oxidationat higher operating temperature and chemical reaction with parent materials. The various WS_2 solid lubricant properties are physical properties (adhesion restriction), chemical properties (oxidation resistance), mechanical prop-

Table 2: Experimental results.

S. No.	Tool diameter (mm)	Tool rotation speed (rpm)	Step size (mm)	Conventional fluid			Solid lubrication		
				Ra (µm)	Time (min)	T (°C)	Ra (µm)	Time (min)	T (°C)
1	8	700	0.2	2.07	37	414	1.83	33	407
2	8	1100	0.4	1.52	16	416	1.29	11	412
3	8	1500	0.6	1.81	8	431	1.67	6	427
4	12	700	0.4	1.32	11	371	1.02	9	363
5	12	1100	0.6	1.65	16	384	1.42	11	375
6	12	1500	0.2	1.91	26	392	1.78	21	387
7	16	700	0.6	1.84	10	341	1.54	8	336
8	16	1100	0.2	1.55	20	356	1.28	17	338
9	16	1500	0.4	1.12	15	364	0.98	12	345

erties (lower shear strength), and micro structural (lamellar structure-II) [13]. It is observed that for WS_2 solid lubricant, properties like low value of coefficient of friction and better lubricity reflected in the surface roughness results. Nano powder mixed cutting fluid is used to enhance the thermal conductivity of the base fluid. Also, it provides a rolling action between mating surfaces and enhances the tribological properties. Effective lubrication and cooling were noticed with nano lubrication. Nanoparticles mixed with cutting fluids are easy to spread, absorb, squeeze, and lead to better lubrication film. This will be useful for effective cooling and enhancement of machining.

Effect of process parameters

Tool diameter and its variation studies are used to understand the mechanism of deformation and surface quality in SPIF. The diameter of forming tool with lower value generates localized region and chance to burns the sheet. In the case of larger diameter, dissipate the heat in relatively higher from the SPIF zone [14]. Surface roughness is increased when the tool rotation speed is increased. This might be due to high frictional heat generation because of higher value of rotation speed. This frictional heat is used to create thermal expansion of solid lubricant and forms thin lubrication film [15]. Step size influences the thickness distribution and time taken for forming process. From the results it is observed that higher heat distribution is possible with small value of step size. The smaller value of step size can lead to temperature rise as well as time taken for performing the process. Formability and surface quality are influenced by step size. Higher value of step size induces more surface roughness due to more waviness formation between the successive counter of the tool path [16]. Tool rotation speed is used for deformation of the sheet during the process without need of any other additional heat devices. A higher range of tool rotation gives more frictional heat during the forming process. At higher tool rotation speed, more heat is generated which is used to deform the sheet and excess temperature will be removed with the help of lubrication introduced by solid lubrication [17].

Conclusions

- In this work, two different cutting conditions are considered, and the process performance is analyzed. A comparison investigation is executed on SPIF process using conventional fluid and nano powder mixed solid lubrication.
- Nano powder mixed solid lubrication is performed better in terms of surface quality and working zone temperature. The significant properties of tungsten disulfide are easy smear, brittle, low value of shear strength. Al_2O_3 nano powder is easily available, low cost, and has better tribological properties. The combined advantages are enhanced machining performance.
- Thin film lubrication layer due to thermal expansion of solid lubricant leads to better surface quality and working zone temperature. It is understood that nano solid lubrication can be suggested as an alternative to conventional cutting fluid. Mist clouds are generated during the machining process due to nanofluid. Also, there is a rolling mechanism in between mating surfaces. These will be useful to reduce frictional effect during the machining process.
- The main effect plot indicates the lower value of step size as 0.2 mm, higher value of spindle speed 1500 rpm and larger tool diameter of 16 are the significant process parameters.
- The step size influences waviness and heat distribution, spindle speed influences the heat dissipation and tool diameter influences the heat dissipation.

Acknowledgements

The AICTE-MODROB initiative provided financing support, which is appreciated by the writers. F. No. 9-226/IDC/MODROB/Policy-1/2019-20 is the reference number.

Conflict of Interest

None.

References

1. Diabb J, Rodríguez CA, Mamidi N, Sandoval JA, Taha-Tijerina J, et al. 2017. Study of lubrication and wear in single point incremental sheet forming (SPIF) process using vegetable oil nanolubricants. *Wear* 376: 777-785. https://doi.org/10.1016/j.wear.2017.01.045
2. Kilani L, Mabrouki T, Ayadi M, Chermiti H, Belhadi S. 2020. Effects of rolling ball tool parameters on roughness, sheet thinning, and forming force generated during SPIF process. *Int J Adv Manuf Technol* 106(9-10): 4123-4142. https://doi.org/10.1007/s00170-019-04918-1
3. Krishna PV, Srikant RR, Rao DN. 2011. Solid lubricants in machining. *Proc Inst Mech Eng Part J J Eng Tribol* 225(4): 213-227. https://doi.org/10.1177/1350650111398172
4. Divya C, Raju LS, Singaravel B, Niranjan T. 2022. Performance investigation of micro hole textured cutting inserts on power consumption and its measuring methodology in turning process. *Alexandria Eng J* 61(4): 3125-3130. https://doi.org/10.1016/j.aej.2021.08.043
5. Sterle L, Kalin M, Pušavec F. 2018. Performance evaluation of solid lubricants under machining-like conditions. *Procedia CIRP* 77: 401-404. https://doi.org/10.1016/j.procir.2018.08.299
6. Mosleh M, Atnafu ND, Belk JH, Nobles OM. 2009. Modification of sheet metal forming fluids with dispersed nanoparticles for improved lubrication. *Wear* 267(5-8): 1220-1225. https://doi.org/10.1016/j.wear.2008.12.074
7. Sornsuwit N, Sittisakuljaroen S. 2014. The effect of lubricants and material properties in surface roughness and formability for single point incremental forming process. *Adv Mater Res* 979: 359-362. https://doi.org/10.4028/www.scientific.net/AMR.979.359
8. Pavani PNL, Pola Rao R, Srikiran S. 2015. Performance evaluation and optimization of nano boric acid powder weight percentage mixed with vegetable oil using the Taguchi approach. *J Mech Sci Technol* 29: 4877-4883. https://doi.org/10.1007/s12206-015-1035-8
9. Singh RK, Sharma AK, Dixit AR, Tiwari AK, Pramanik A, et al. 2017. Performance evaluation of alumina-graphene hybrid nano-cutting fluid in hard turning. *J Clean Prod* 162: 830-845. https://doi.org/10.1016/j.jclepro.2017.06.104
10. Öndin O, Kıvak T, Sarıkaya M, Yıldırım ÇV. 2020. Investigation of the influence of MWCNTs mixed nanofluid on the machinability characteristics of PH 13-8 Mo stainless steel. *Tribol Int* 148: 106323. https://doi.org/10.1016/j.triboint.2020.106323

11. Padmini R, Krishna PV, Mohana Rao GK. 2015. Performance assessment of micro and nano solid lubricant suspensions in vegetable oils during machining. *Proc Inst Mech Eng Part B J Eng Manuf* 229(12): 2196-2204. https://doi.org/10.1177/0954405414548465
12. Ze W, Jianxin D, Yang C, Youqiang X, Jun Z. 2012. Performance of the self-lubricating textured tools in dry cutting of Ti-6Al-4V. *Int J Adv Manuf Technol* 62: 943-951. https://doi.org/10.1007/s00170-011-3853-x
13. Krishna PV, Rao DN. 2008. Performance evaluation of solid lubricants in terms of machining parameters in turning. *Int J Mach Tools Manuf* 48(10): 1131-1137. https://doi.org/10.1016/j.ijmachtools.2008.01.012
14. Zareh-Desari B, Davoodi B. 2016. Assessing the lubrication performance of vegetable oil-based nano-lubricants for environmentally conscious metal forming processes. *J Clean Prod* 135: 1198-1209. https://doi.org/10.1016/j.jclepro.2016.07.040
15. Azevedo NG, Farias JS, Bastos RP, Teixeira P, Davim JP, et al. 2015. Lubrication aspects during single point incremental forming for steel and aluminum materials. *Int J Precis Eng Manuf* 16: 589-595. https://doi.org/10.1007/s12541-015-0079-0
16. Vahdani M, Mirnia MJ, Gorji H, Bakhshi-Jooybari M. 2019. Experimental investigation of formability and surface finish into resistance single-point incremental forming of Ti-6Al-4V titanium alloy using Taguchi design. *Trans Indian Inst Met* 72: 1031-1041. https://doi.org/10.1007/s12666-019-01577-4
17. Kumar A, Gulati V. 2019. Experimental investigation and optimization of surface roughness in negative incremental forming. *Measurement* 131: 419-430. https://doi.org/10.1016/j.measurement.2018.08.078