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Turning process assisted in situ by short time current pulses

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Abstract

This article reports on a novel machining process technique: in situ electrically assisted turning process based on the influence of electropulsing. An in house generator was used to induce a current intensity of 90 A, a pulse duration between 50 and 200 µs and frequencies between 100 and 300 Hz. The influence of different electropulsing configurations assisting the machining process was studied, specifically on the surface properties and the power consumption in 1045 steel. The results show that the electrically-assisted turning process improves material machinability, decreasing the power consumption up to 104 W and the specific cutting energy up to 22%. The assisted process also modifies the surface properties, the average surface roughness decreases within the range of 7 to 22% when compared to the conventional turning process.

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Keywords: electropulsing;electroplasticity; surface roughness; plastic side flow; power consumption

1. Introduction

Surface hardness during the machining process is defined by the material elastoplastic behaviour. During the turning process, prior to starting the chip removal and due to the elevated primary shear stress values, plastic strain is initiated in the material which is in contact with the principal face of the cutting tool. These stresses generate a plastic movement of the material called plastic side flow, which tend to create pile up on the secondary face of the cutting tool. This phenomenon generates greater peaks and valleys in roughness as described by Liu and Melkote

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[1]. The in situ high current density electropulsing assisted turning process is a novel technique that could solve this problem.

Electroplasticity has demonstrated that it reduces the stress necessary to create plastic strain in a material. Stolyarov [2] proved that the ultimate tensile strength decrease and Tang et al. [3] stated that the material elongation increase. Furthermore, it has been shown by Salandro et al. [4] that it attenuates the elastic recovery of the material. A previous study, Sanchez et al. [5], have been proved that the material´s formability improves after being plastic deformed. The electropulsing assisted turning process intends to improve surface roughness compared to the conventional process primarily due to two reasons. First, electroplasticity will influence the major shear stresses needed to start the chip removal, those stresses were studied by Khidhir and Mohamed [6]. The decrease in the shear stress is accompanied by a lower plastic side flow effect, which will induce less pile up on the secondary face of the material and therefore a lower average roughness (Ra). Secondly, electroplasticity affects the elastic recovery of the material by attenuating this feature, as it was proved by Green at al. [7]. These authors affirm that the elastic recovery of the material is reduced when the thermal and athermal phenomena of electroplasticity are present. This is the other factor which can improve surface roughness in the machining process.

This article will study the high current density electropulsing assisted turning process, paying special attention to the athermal effects of electroplasticity. A novel current pulse generator was designed and created with the goal of minimizing the Joule effect of electroplasticity. These current pulses will be induced in SAE 1045, while a turning process of roughing and finishing is performed. The impact of the current pulses will be analyzed on the power consumed and surface roughness. The goal is to study if differences are presented between the conventional turning process when compared with the electropulsing assisted turning process.

2. Methodology

The commercial material used in the current study is SAE 1045. The metallic cylindrical bars dimensions were 190 mm in length and 25 mm in diameter. Turning test was performed on a TOZ, ZPS-R5 lathe. A tungsten carbide TNMG-16 tool with 0.8 mm nose radius and a cutting edge angle of 0° and a MTJNR 2525 M16 tool holder were used to turn the metallic bars. The machining parameters used are shown in Table 1.

Table 1: Turning operation parameters.

Material	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
SAE 1045	460	0.046 / 0.127 / 0.254/ 0.356	0.25

The power consumed was continuously registered with a Fluke 434 energy analyzer. The sampling rate was 200 KS/s with storage every 0.5 s. The surface roughness was measured with a rugosimeter (Mitutoyo SJ-201). A self-made short current pulse generator was manufactured to discharge multiple positive pulses. The parameters of the current such as frequency, density and pulse duration were monitored by an oscilloscope. The current pulse parameters used and the material maximum temperature measured are listed in Table 2.

In order to electrically assist the turning process in situ a couple round conventional turning operations were previously done on each workpiece. This procedure will ensure the workpiece concentricity and the optimal electric contact of the cutting tool and the carbon clamps during the turning process. Later, a round turning operation without electric pulses (conventional process) of 45 mm length was done. Subsequently, the same procedure was performed but assisted with electric pulses (assisted process). Therefore, the power consumption, surface roughness and material hardness of both processes have been compared.

Table 2: Electropulsing operation parameters and maximum bulk temperature.

Material	Current intensity (A)	Pulse duration (μs)	Frequency (Hz)	Max. Temperature (°C)
SAE 1045	90	50 / 200	100 / 300	138,5

3. Results and discussion

3.1 Surface roughness

The average roughness Ra results obtained are shown in Figure 1. In the Fig. 1a the experiments performed with 200 μs pulses are shown. In the Fig. 1b the experiments performed with 50 μs pulses are shown. The average roughness measured is shown in Figure 1a and 1b. In these figures, the machining process without pulses is compared with the pulse assisted process. The experimental values of the average roughness are the result of 5 measurements performed in different parts of the workpiece. Each point of the graphic represents the average of these values. The error bars define the confidence interval with a 95% probability. The continuous line represents the calculated geometric roughness with the equation $\mathrm{Ra} = 31.25 \cdot \mathrm{f}^2/\mathrm{r_h}$commonly used to estimate the average roughness Ra (μm) [8], where f represents the feed rate (mm/rev) and rh the cutting tool nose radius (mm).

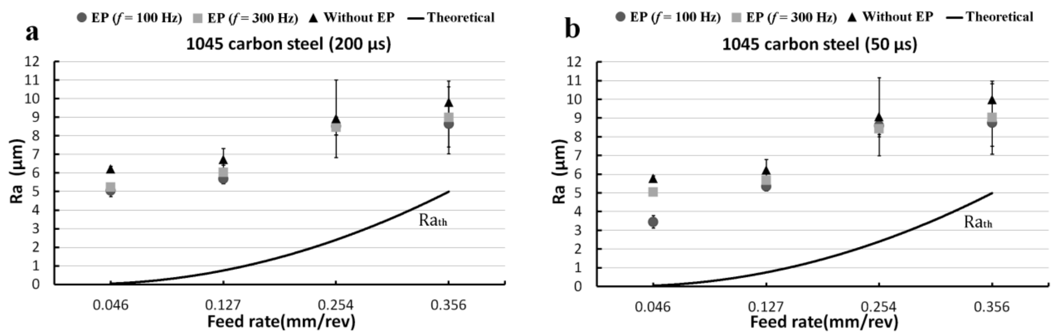

Fig. 1. Average roughness values SAE 1045 (a-b).

The workpieces assisted by current pulses and 0.046 mm/rev feed rate show a better surface finished than those machined conventionally. The average registered decrease in Ra was 22%. The roughness registered in the machined workpieces with intermediate feeds (0.127 and 0.254 mm/rev) also improves when the process is assisted with electric pulses. But the difference found compared to the conventional process is not as large as in the lower feed rates. For 0.127 mm/rev feed rates, the decrease in average roughness Ra presented was 12%. While for 0.254 mm/rev feeds the decrease in average roughness presented was 7%. Lastly, if it is analyzed the roughness registered in machined workpieces with high feed rates (0.356 mm/rev) the roughness generally presents modest improvements when the process is assisted with current pulses. The difference found with regards to the conventional process is not significant, the Ra values of the different populations are generally found within the error bars. Even so, the decreases registered of the population means for Ra were 10%.

If the results obtained are compared according to the influence of the frequency and the duration of current pulses on the roughness, it is observed that the range of values used do not present statistically significant differences. As such, the different electric configurations used do not ensure that a greater frequency or duration improves the surface roughness, at least in the frequency ranges between 100 – 300 Hz and pulse duration between 50 - 200 μs. Even so, the assisted process always presents surface roughness results lower than the conventional process.

Zhang et al. [9] reported that the average roughness decreased between approximately 20% and 30% when the process is previously assisted with current pulses. The electric parameters used were: current density between 274 and 347 A/mm2, frequency between 151 and 294 Hz and with a pulse duration of 70 μs. These results are similar to those obtained in the present study. It can be concluded that previous pulses as well as the in situ pulses improve the surface roughness of the machined material.

3.2 Power consumption

The power consumed during the cutting process was measured by the energy quality analyzer (Fluke 434). The net active power Wn is determined by subtracting the starting basal power from the average power when the cutting tool is removing material. In this section, the net active power obtained is compared in a conventional turning process with respect to the power obtained in an assisted turning process. The hypothesis in question is: the net active power consumed by the motor in an assisted turning process is less than the power consumed by the conventional process. The cutting conditions for this experiment are: 0.127 mm/rev feed rate, 1 mm depth of cut, 300 Hz pulse frequency and 200 µs pulse duration.

The initial power peak represents the engine start. Then, the active power consumed by the conventional round turning process in rough machining. At 160 seconds, a decrease of approximately 100 W in the power consumed was registered due to the application of electric pulses (assisted process). The power consumed by turning in space, with no machining is 1,509 W.

In Figure 2 the reduction in power consumed is shown, defined as the difference between the net active power of conventional turning and the net active power of a pulse assisted turning process (Wn - Wne). Figure 2a shows the experiments performed with 200 µs pulses and two frequencies 100 and 300 Hz. Figure 2b shows the experiments performed with 50 µs pulses and frequencies mentioned above. The power values shown in each case are the average of 3 values registered during the round turning operation. The error bars define the standard deviation of these values.

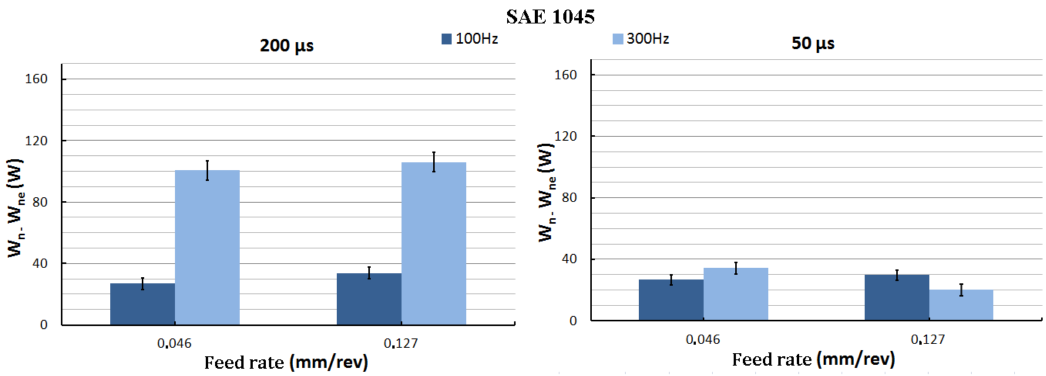

Fig. 2. Power consumption comparison between conventional and assisted process for pulse durations of (a) 200 µs and (b) 50 µs.

In all the cases studied, the application of electric pulses has been observed to reduce the power consumption of the engine. The maximum reduction of power consumed was 108 W for a 0.127 mm/rev feed rate, 200 µs pulses at 300 Hz charge frequency. On the other hand, for the 0.046 mm/rev feed rate, with 50 µs pulses and 300 Hz frequency, the least power reduction was obtained, 20 W. The use of pulses with greater duration shows a larger reduction of the power consumed, especially if combined with high frequency values. For these cases, the power consumes tends to decrease about 104 W on average. For current pulses of lesser duration, the power consumed is attenuated, independently of the frequency utilized.

The energy consumed by the electric pulse generator is the sum of the energy provided in each pulse 58.6 W (for a 200 µs pulse duration and 300 Hz frequency) plus the energy consumed by the electronic control 8 W. This sum is less than 104 W, which is the energy saved in the assisted process. If we take the energy consumed as the reference, the assisted turning process is more efficiently than conventional turning.

Sood et al. [10] defined that the specific cutting energy, the energy per unit of volume removed, is calculated as the quotient of the net energy and the material removal rate. In the Figure 3 is showed the assumption of the cutting removal section of the machined workpiece.

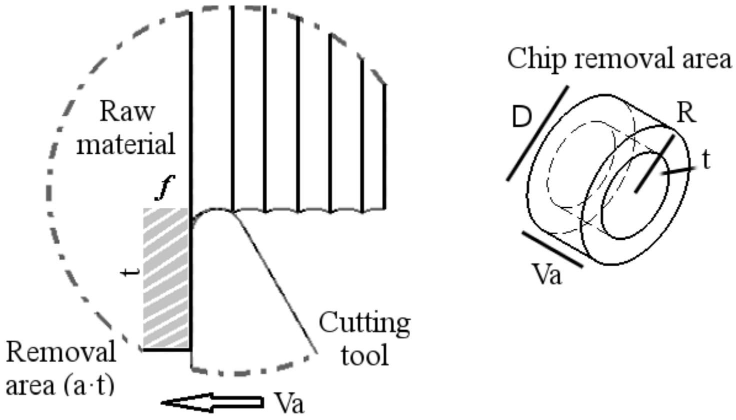

Fig. 3. Assumption of the cutting removal section.

The material removal rate is a function of the cutting conditions and of the operation performed. For a turning operation the material removal rate *Qc* is:

$$Qc = S \cdot f \cdot t \cdot \left(1 - \frac{t}{D}\right), \quad (1)$$

where S is the spindle speed (rpm), f is the feed rate (mm/rev), t is the depth of cut (mm) and D the diameter of the cylinder (mm).

To compare the assisted process with the traditional process the percentage of reduction rp experienced in the specific cutting energy is evaluated. This reduction is defined as:

$$r_p = \frac{E_s\,(conventional) - E_s\,(assisted)}{E_s\,(conventional)}, \quad (2)$$

where Es is the specific cutting energy (W·s/mm3).

In Table 2 the reduction values obtained for the specific cutting energy are presented in percentages, calculated from the previous equation for 0.046 and 0.127 mm/rev feeds, 50 and 200 μs pulse durations and 100 and 300 Hz frequencies.

Table 3: Specific cutting energy percentage reduction.

f (mm/rev)	0.046				0.127			
Frequency (Hz)	100	100	300	300	100	100	300	300
Duration (μs)	50	200	50	200	50	200	50	200
SAE 1045 (%rp)	7.68	8.3	9.71	21.84	8.24	8.94	4.77	11.37

The maximum specific energy reduction is approximately 22%, independent of the feed used and for current pulses of 200 μs and a 300 Hz frequency. As such, the largest decrease in specific cutting energy is produced when the process is assisted in situ combining high frequency charges and a greater pulse duration. If the results are composed with those presented by Zhang et al. [9] the maximum decrease in specific energy was 54%, precisely when previously in the rolling process high frequency pulse currents are applied.

4. Conclusions

The electrically assisted turning process has been shown to be a feasible technique to improve the material machinability compared with the conventional turning process.

The surface roughness improves when the turning process is electrically assisted, especially when higher pulse duration and smaller feed rates are used. The power consumption and the cutting specific energy were reduced with the current pulses presence. The impact is particularly noticeable for high frequencies and long pulse duration.

The frequency and pulse duration seem to have an influence on improving the material machinability, but further studies need to be done with higher frequencies and longer pulse durations to determine the contribution tendencies of such parameters. However, when the process is assisted by electric pulses, the reduction in the energy consumed by the spindle is always greater than the energy consumed by the pulse generator.

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