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SIMULATION AND EXPERIMENTAL RESULTS ON THE TEMPERATURE DURING TURNING PROCESS OF COMMERCIALLY PURE TITANIUM

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Abstract: *The turning of pure titanium can be considered, from point of view of machining, a very difficult material, due to low thermal conductivity and thermal diffusivity, but not only. For this reason temperature during the turning process is a very important task in the factors evaluation of the turning process, and can affect the tool wear and sometimes can produce structural modification.*

In this paper the temperature during the turning process of pure titanium is analysed, using two methods, simulation and experimental determinations. In order to obtain the correct results, for the simulation and experiments, the same cutting parameters were used, and also, in the case of experiments, the emissivity of pure titanium was determined.

Key words: *Simulation, Experimental results, Temperature, Emissivity, Pure Titanium*

1. INTRODUCTION

As it is known, the grades for commercially pure titanium are 1, 2, 3 and 4, having minimum titanium 99%. From the point of view of applications, pure titanium, grade 2 is used in a large area as food, chemical, automotive industry, mechanical and architecture parts, but also marine and medical industry, [1], [2].

The turning process of the pure titanium can be considered a difficult one, especially due to the physical properties. The low values for thermal conductivity, but also the thermal diffusivity can conduct to an intense heat in the cutting area, and sometimes structural-phase transformations in the surface layer, [1].

Also, is important to add that the low conductivity restricts the use, during the cutting process of the high-speed machining, the suggested values being in the range of (30-60) m/min, when using, carbide inserts. The high values of the cutting speed can conduct to the high values of temperature, and, consequently, rapid tool wear, [3]

From point of view of temperature, in [4] are analyzed the performance of two types of inserts, ceramic and CBN, in turning ~~of~~ a titanium alloy, while in [5], is analyzed the influence of the tool tip temperature on the wear for ceramic inserts, having different hardness.

In [6] the authors used simulations tool to obtain the temperature at tool-chip interface in orthogonal turning process.

In [7] the authors compare the temperature during the turning process using the measured temperature with the one obtained by simulation for turning with coated carbide inserts.

Researches on the cutting temperature, for coated and uncoated inserts are done, also, in [8] and [9]. So, in [8], in order to obtain the useful data for optimization of cutting parameters, based on the two methods, with thermocouple and infrared based sensors, for coated carbide, as tool, they found that the increase of temperature is due to the increasing of speed, feed and depth of cut, while in [9] the authors, using coated and uncoated carbides tool, proceed to measure the turning temperature on the rake face using work thermocouple, and show that the increasing of the temperature is due to the increasing the cutting speed and feed rate.

Based on literature review, the authors show that the temperature, during turning process, is mainly influenced by the cutting speed and this influence is not linear, [10],

In [11], the authors study the dependence of the measured temperature on the emissivity, measured using the direct radiometric method for uncoated P10 tungsten carbide inserts, as a function of the surface roughness and the oxidation state.

Based on a thermocouple and an infrared sensor-based measurement for dry machining with coated carbide insert of alloy steel, in [12], the authors showed the increasing of temperature with increasing of cutting speed, feed rate and depth of cut. They show that the results obtained can assure useful data for the optimization of the cutting parameters in orthogonal machining.

Also, in [13] the authors used Finite Element Method and a non-contact method, with an Optical Infrared Pyrometer, to study the cutting temperature during turning process and compare the temperature results between experiments and simulation

For the present paper, the temperature during the turning process of commercially pure titanium, grade 2 is analyzed using both simulation and experimental procedure.

For this reason, the simulation analysis was done using the same turning parameters (cutting speed, feed rate, and depth of cut) as in the experimental conditions.

The aim of this study is to compare the correctness of the experimentally results.

2. SIMULATION OF THE TEMPERATURE DURING THE TURNING PROCESS OF PURE TITANIUM

In order to compare the experimental results with those ~~are~~ obtained using the simulation of the turning process of pure titanium, an adequate program is used for Finite Element analysis. To perform the turning simulation, the next steps were followed: the defining of the materials, both for work-piece and tool, pure titanium and carbide alloy, respectively.

Also, the tool geometry with rake angle, $\gamma = 5^0$, relief angle, $\alpha = 5^0$, and the nose radius, $r_\varepsilon = 0.8$ mm, was defined.

From point of view of cutting fluid, this simulation was performed in the dry conditions, as in the experimental determinations.

So, from point of view of the turning parameters, the values of the cutting speed are variable, 141 m/min (that corresponds to 1000 rpm), 99 m/min (that corresponds to 700 rpm), and 69 m/min (that corresponds to 490 rpm), and the feed rate and depth of cut are constant with the values, 0.09 mm/rot and 2 mm, respectively.

After these input data, for the structure (tool-work-piece), the mesh was applied, and then, after the running process of simulation, the next results were obtained, fig. 1 to fig. 3.

For the first set of cutting parameters (141 m/min, 0.09 mm/rot and 2 mm), fig. 1, the simulation indicates the maximum values of the temperature 604.474 ^{o}C. For the second set (99 m/min, 0.09 mm/rot and 2 mm), the maximum values of the temperature was 543.273 ^{o}C, fig. 2. For the last set (69 m/min, 0.09 mm/rot and 2 mm), the maximum value of turning temperature was 480.53 ^{o}C, fig. 3.

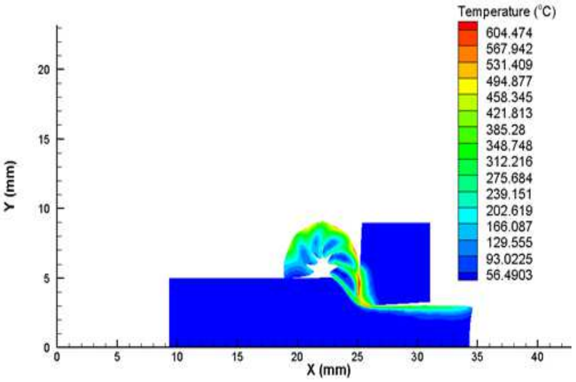

Fig. 1. Temperature field for the values of the cutting speed, 141 m/min, feed 0.09 mm/rot, depth of cut, 2 mm

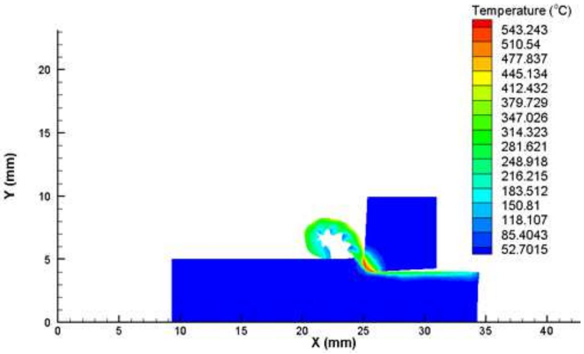

Fig. 2. Temperature field for the values of the cutting speed, 99 m/min, feed 0.09 mm/rot, depth of cut, 2 mm

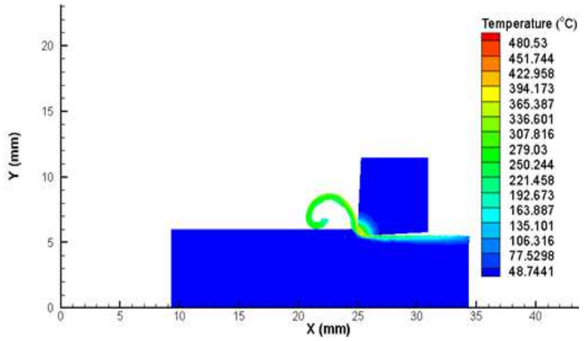

Fig. 3. Temperature field for the values of the cutting speed, 69 m/min, feed 0.09 mm/rot, depth of cut, 2 mm

3. EXPERIMENTAL DETERMINATIONS

3.1. Experimental conditions

In order to measure the temperature during the turning process of titanium, an experimental installation was used. It consists, fig. 4, of a non-contact infrared thermometer Optris CT 3MH1, [14], titanium bar having ϕ 45 mm diameter and single point tool with uncoated carbide insert KCU10 grade, code CNMG 12 04 08 MS, support insert, cod CNMG 432MS, all assembled on a toolholder DCLNR 2020K12KCO 4.

The physical properties of the commercially pure titanium are presented in Table 1.

Table 1

Physical properties of pure titanium, grade 2

Material	Hardness HRBW	Physical properties		
		Thermal conductivity λ, w/m·K	Specific heat, c, J/Kg·C	Density ρ Kg/m^3
Pure Titanium	80	171	473	4.5

All the experiments were performed using the lathe Bernardo Master 400 type, with digital readout.

3.2. Emissivity determination

Because the emissivity value can affect the measurement results is important to know the exact value for pure titanium.

For this reason, an adequate installation was proposed, and it consists of a digital thermometer [15], two calibrated thermocouples, coupled to the pure titanium sample and the Optris CT 3MH1 infrared thermometer. On this way, the sample temperature was measured using two methods: by contact with the thermocouples and non-contact using infrared thermometer,

The sample was previously machined by milling so that the surface roughness is known by measurement.

The titanium sample has been heated, the temperature values being measured with two calibrated thermocouples, in contact with the sample, and was read on the digital thermometer, fig. 5. The two thermocouples were installed, using two holes drilled very close to the middle of the sample.

Due to the stability of the thermal process, the thermal inertia was not taken into account.

Then, the emissivity value was adjusted, using the infrared thermometer until the temperature value, as it can see in the fig.7 indicated the same temperature or close to that indicated on the digital thermometer, fig. 6.

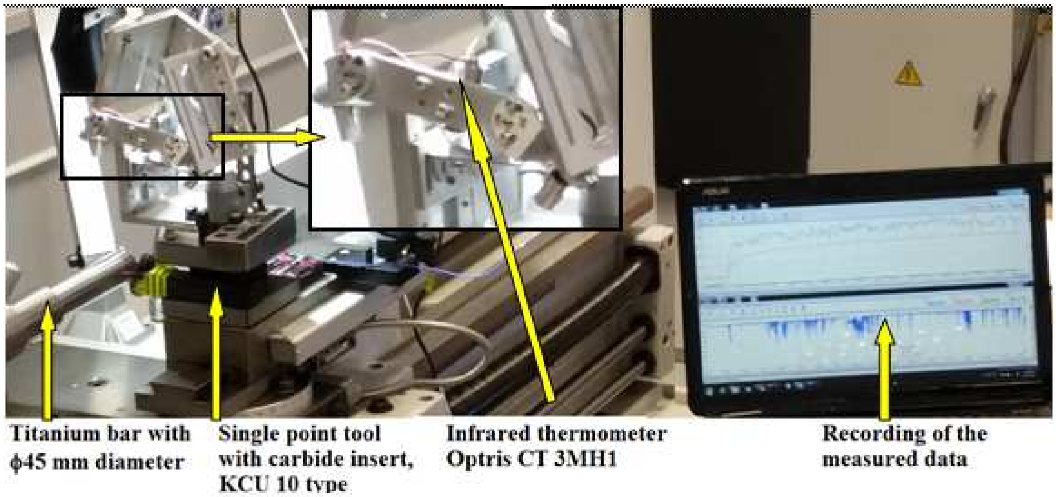

Fig. 4. Experimental installation with the detail window for the infrared thermometer

Fig. 5. The temperature values of the heated sample indicated at the digital thermometer

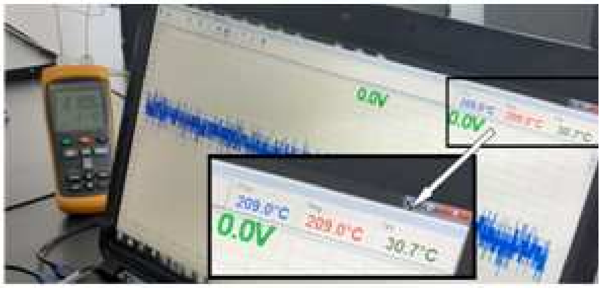

Fig. 6. The emissivity adjusting for the infrared thermometer Optris CT 3MH1

On this way, it was possible to adjust the emissivity at the value of ε = 0.129.

Graphically, in fig. 7 is presented the variation of the temperature registered at the infrared thermometer Optris CT 3MH1, for this value of the emissivity.

The maximum values of the temperature indicated, using infrared thermometer, is 209°C, as it is sown in fig. 6 and fig. 7.

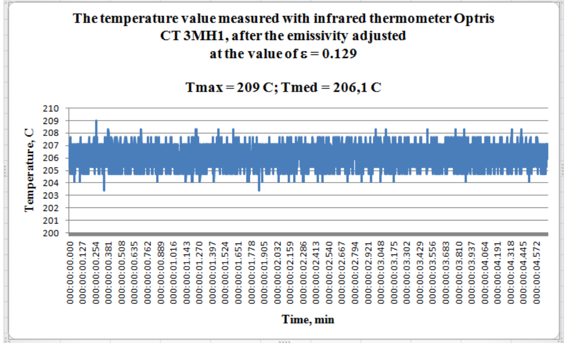

Fig. 7. The temperature values measured with infrared thermometer after the emissivity adjusting

4. RESULTS

Using the experimental installation presented in fig. 4, and the adjusting of the emissivity at the value of ε = 0.129, the next results were obtained, for the each set of cutting parameters.

The cutting parameters were the same ones that were used for turning simulation: different cutting speed (v = 141, 99 and 69 m/min), feed and depth of cut, was keeping constant at the values of 0.09 mm/rot and 2 mm, respectively.

The graphical representations are presented in fig. 8 to fig. 13. It is important to mention that fig. 8 to fig.10, represents the capture of primary records from Optris CT 3MH1 infrared thermometer.

Using these primary records, all the data were processed using Excel program and the results are presented in fig. 11 to fig. 13.

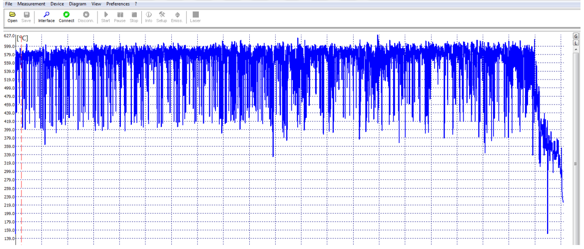

Fig. 8. Capture during registered temperature with Optris CT 3MH1 at v = 141 m/min

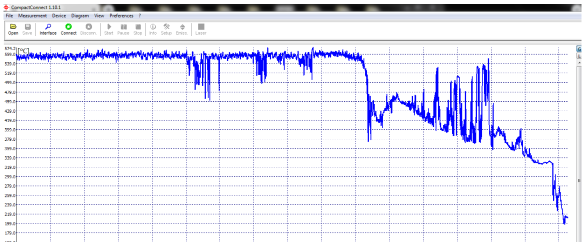

Fig. 9. Capture during registered temperature with Optris CT 3MH1 at v = 99 m/min

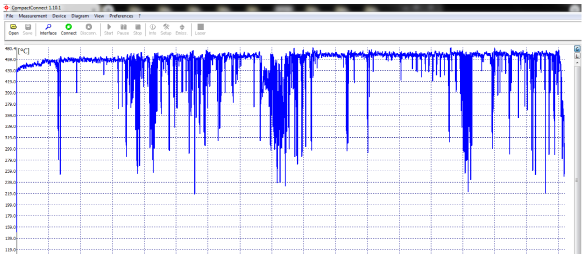

Fig. 10. Capture during registered temperature with Optris CT 3MH1 at v = 69 m/min

It is important to add that for each set of the cutting parameters, three determinations were performed. In order to estimate the difference between simulation and experimental determinations, synthetically, in fig. 14 are presented the obtained values.

5. CONCLUSIONS

In this paper the temperature during turning process of commercially pure titanium, grade 2, is analysed, using the simulation and experimental determinations. For this reason the same cutting parameters, in terms of cutting speed, feed and depth of cut, were used

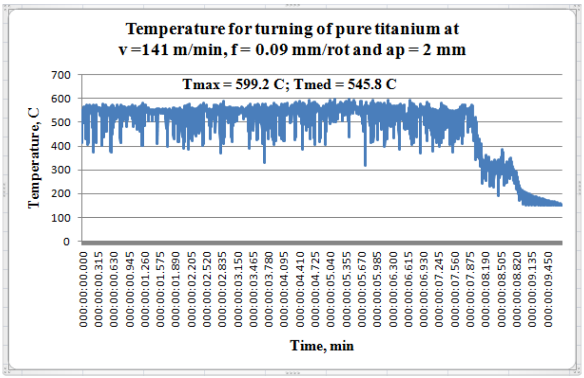

Fig. 11. Measured temperature with the Optris CT 3MH1 infrared thermometer for cutting speed 141 m/min

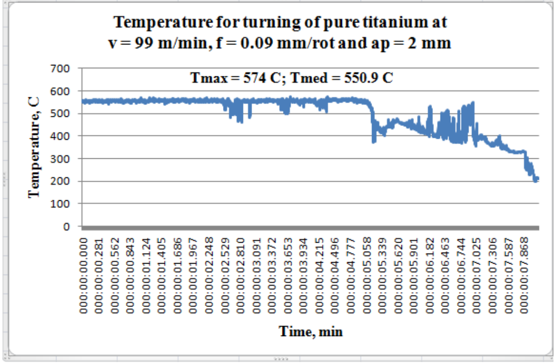

Fig. 12. Measured temperature with the Optris CT 3MH1 infrared thermometer for cutting speed 99 m/min

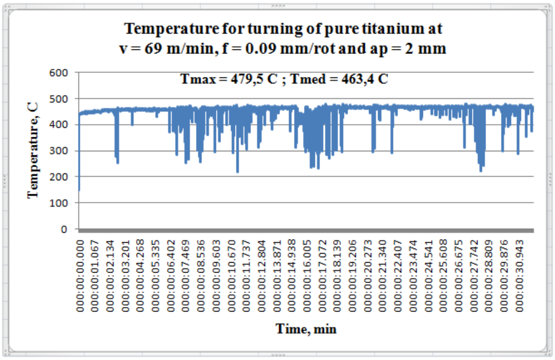

Fig. 13. Measured temperature with the Optris CT 3MH1 infrared thermometer for cutting speed 69 m/min

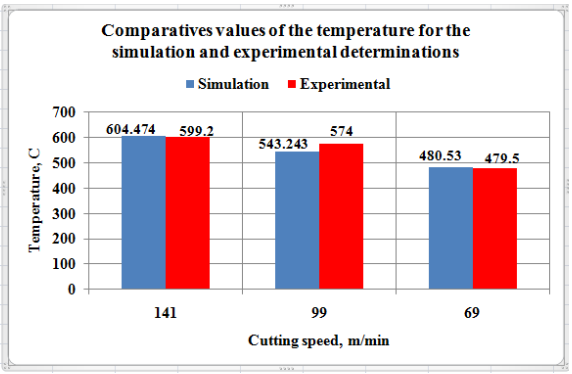

Fig. 14. Comparative values of the temperature for the simulation and experimental determination

In order to obtain the correct results of temperature, an adequate installation for the emissivity of the pure titanium determination, was used, fig. 5 to fig. 7.

From point of view of the temperature values, as it can see from the fig. 1 to fig. 3, and fig. 14, after the simulation process, the maximum values of the temperature, 604.474 °C, was obtained for the higher value of cutting speed, 141 m/min, and the lower value 480.53 °C, for the lower value of cutting speed, 69 m/min.

For the experimental determinations, an installation were used, fig. 4 and the measured values, are graphically present in fig. 11 to fig. 13, and fig. 14.

So, for the value of cutting speed, the maximum value was 599.2 °C, and the minimum value, 479.5 °C, was obtained for 69 m/min.

As it can see, fig. 14, the differences from the temperature values after the simulation and experimental determinations are small, slightly larger for simulation, except the value of cutting speed, 99 m/min, where the value of the temperature is higher in this case of the experimental determinations.

For the both, the simulation and experimental determinations, the higher value of the cutting speed produce a higher temperature for the turning process.

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Simulare și rezultate experimentale privind temperatura în timpul procesului de strunjire a titanului pur comercial.

Rezumat: Strunjirea titanului pur poate fi considerata, ca proces de prelucrarea, foarte dificil și aceasta datorită conductibilității termice reduse dat și difuzivității termice și nu numai. Pentru acest motiv, temperatura dezvoltată în timpul procesului de strunjire reprezintă un aspect important în evaluarea factorilor ce influențeaz procesul de strunjire și care poate afecta uzura sculei dar și cauza modificări structurale ale materialului de prelucrat.

În această lucrare este analizată temperatura din timpul procesului de strunjire a titanului pur folosind două metode, respectiv simularea prin analiza cu element finit și determinări experimentale. Astfel, pentru a obține rezultate corecte, atît pentru simulare cît și pentru experimente s-au folosit aceeași parametrii ai regimului de așchiere. În plus a fost nevoie, pentru experimentări și de determinarea experimentală a emisivității.

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