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HEAT GENERATION AND TEMPERATURE IN GRAY CAST IRON DRILLING USING CALORIMETER METHOD

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Abstract: *The objective of this study is to establish the relationship between the mechanical energy consumed and heat generated in gray cast iron drilling using the calorimetric method. The calorimeter consists of two cylindrical containers, the external of Technyl® and internal of PVC (Polyvinyl Chloride). Between the two containers is added Expanded Polystyrene (Isopor®) for thermal insulation. T thermocouples are used for measuring the temperature. Rotating dynamometer was used for measuring torque. The cutting tool is a twist drill (high-speed steel) coated of TiAlN with 10 mm diameter. Cutting fluid wasn't used. Preliminary results were promising, showing that the proposed calorimeter can be used to assess the heat generated in cast iron drilling.*

Keywords*: calorimeter, heat, temperature*

1. INTRODUCTION

There is consensus among researchers that the energy consumed in the cutting is converted, for the most part, in heat (Shaw, 1984; Trent; Wright, 2000). This thermal power increase becomes a critical parameter in the process, resulting technical and economic problems mainly due to the heat dissipated by cutting tool, limiting its useful life. For example, in machining alloys with high melting point such as titanium and nickel super alloy, the cutting tools are heated to high temperatures, due to the removal rate of material can fail catastrophically under the influence of tensions and temperatures after short machining time (Ferraresi, 1970; Trent; Wright, 2000; Machado *et al.*, 2011).

Heat generated in the cutting was investigated in a pioneering work by physicist Benjamin Thompson (Count Rumford, 1753-1814) in 1798. Noting the manufacture of bronze cannons, Rumford was amazed with large amounts of heat generated in the operation - the piece was dipped in a tank with water, which heated the boiling point (rudimentary calorimeter). Rumford investigated how this amount of heat was produced in a purely mechanical operation, by immersing the piece, cutting tool and chips in a known quantity of water (Komanduri; Hou, 2001).

About fifty years after the Rumford's experiments, the British physicist James P. Joule (1818-1889) developed by calorimetric measurements, the concept of "mechanical equivalent of heat": relationship between mechanical energy and heat when becomes the other one. The equivalent mechanical work is measured by the height of fall of pasta, whereas approximately 4.184 J were needed to raise the temperature 1 °C to 1 g of water. Thus, the mechanical equivalent of water is 4.184 J/cal (Nussenzveig, 2008).

The importance of machining heat study was also of fundamental importance in the experiments of the American engineer Frederick W. Taylor (1856-1915), leading the development of high-speed steel tools. This material is capable of withstanding the higher temperatures that carbon steel tools and multiplied material removal rates by a factor equal to four (Trent; Wright, 2000). Until today the limitations imposed by cutting temperatures has been the stimulus for the development of new cutting tool materials.

Given this cast of historical facts, it is important to understand the factors that influence the generation of heat, heat flow and temperature distribution in the cutting tool and the workpiece. However, heat measurement, temperature and temperature distribution in the cutting area are technically difficult and progress in this area has been slow in over a hundred years since the problem was clearly stated (Trent; Wright, 2000). In this context, this work is proposed in order to present a methodology for assessing the generation of heat and its relation to the mechanical energy expended in machining, especially in the gray cast iron drilling, through the calorimetric method.

2. MATERIALS AND METHODS

The general objective of this research is determine the amount of heat generated and its relationship with the mechanical energy expended in gray cast iron drilling process through the calorimetric method. The methodology used will be presented below.

2.1. Material

The material used was a gray cast iron acquired by *UdiSteel Comércio de Aços Ltda.* in the form of circular section bar with a diameter of 37.0 mm and length of 1.80 m.

2.2. Calorimeter

In this paper was used the calorimeter developed by Silva (2015) in his master's dissertation. The calorimeter proposed consists of two cylindrical containers fitted with each other, the external made of Technyl® and internal of PVC (Polyvinyl Chloride). The outer container has been machined with a fit for insertion of the inner container which, in turn, was machined with a fit for insertion of the specimen. Between the two containers is added Expanded Polystyrene (Isopor®) for thermal insulation.

Calorimeter's lid was built of Technyl®. It's coupled to the inner container of the calorimeter by its salience, attached to the outer container of the calorimeter for six Allen M4 x 10 mm screws. The dimensions of the calorimeter components are shown in Tab. (1).

Table 1: Dimensions of calorimeter components.

Component	External diameter (mm)	Internal diameter (mm)	Diameter of the fit (mm)	Height (mm)
Outer container (Technyl®)	150	122	95	66
Inner container (PVC)	95	60	16	55
Lid (Technyl®)	150	-	60[(1)]	5

[(1)]: In the case of the lid, the feature is a salience.

The samples were cylindrical pieces of gray cast iron with 16 mm diameter and 30 mm height. These were fixed in the lower face, the fit of the internal calorimeter container by Allen M6 x 10 mm screw. In the internal calorimeter was added 90 ml of deionized water (devoid of ions), Fig. (1).

Thermocouples used were cables for type T thermocouple duplex (TT-T-36-100) manufactured by Ômega® with a diameter of 0.127 mm. Thermocouples were welded with capacitive welding and fixed with universal instant adhesive Loctite®.

Equipment for measuring temperature was a 34972A LXI data acquisition/data logger switch unit by Keysight Technologies® control of a computer by Agilent BenchLink Data Logger Pro. The acquisition rate used was 5.88 Hz.

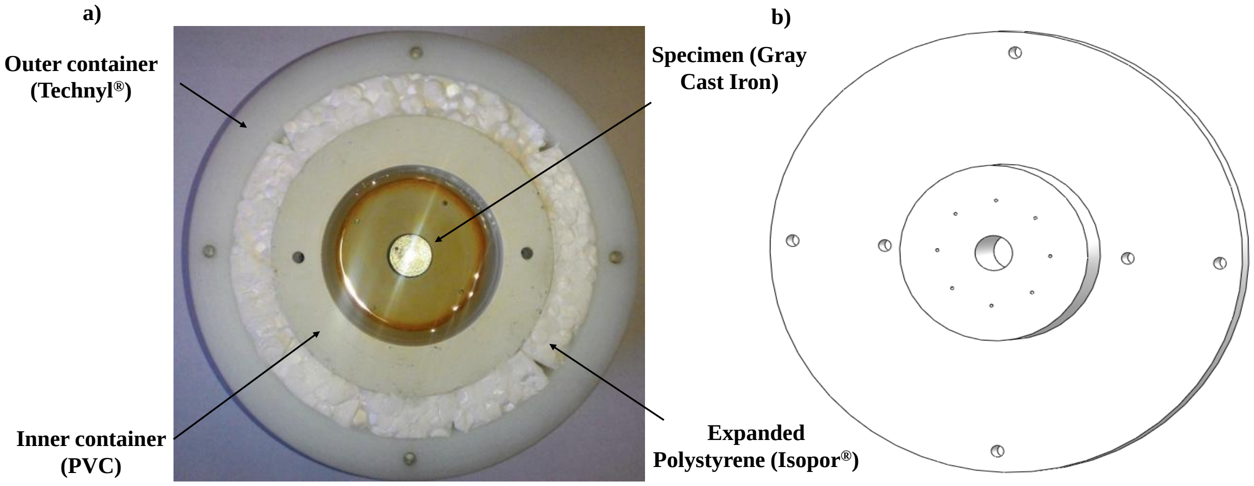

Figure 1: a) Calorimeter fitted with coaxial cylindrical containers. Specimen is fixed by Allen M6 x 10 mm screw; b) calorimeter's lid.

Cutting tool consists of a solid twist drill with two cutting edges. The drill material is high-speed steel/cobalt M42 (8 % Co) coated with TiAlN and manufactured by OSG®.

For measurement of efforts was used Kistler® 9123C1211 rotating dynamometer with Kistler® 5223 multichannel signal conditioner, Fig. (2). The acquisition rate used was 20 Hz.

Kistler® rotating dynamometer

Twist drill high-speed steel coated with TiAlN

Calorimeter

T thermocouples

Figure 2: Acquisition of temperature and torque in the calorimeter.

Machining system used to perform the drilling tests was a Romi® Machining Center Discovery 760 CNC with Siemens® CNC command. The main engine power is 11 kW and maximum rotation is 10,000 rpm.

2.3. Percentage of Mechanical Energy Transformed Into Heat

The initial temperature and the final temperature of the water in the calorimeter are recorded for calculation of heat exchanged inside the calorimeter (ΔQ) by Fundamental Equation of Calorimetry, Eq. (1) (Nussenzveig, 2008):

$$\Delta Q = m\int_{T_i}^{T_f} c(T)dT \equiv m \cdot c \cdot \Delta T \quad [\text{kJ}] \tag{1}$$

Where m is the mass of water (kg) in the calorimeter, c is the specific heat (water worth = 4.1868 kJ/kg.K) and ΔT is the variation of water temperature (K).

The measurement of the torque is used to evaluate the energy consumed (E_{tot}) in all machining process, Eq. (2):

$$E_{tot} = \frac{\pi \cdot \tau \cdot a_f}{f} \quad [\text{kJ}] \tag{2}$$

Where τ is the torque (N.m), a_f is the depth of the hole (m) and f is the feed of the drill (mm/rev).

From the partition of the heat generated by the total energy consumed, by Eq. (1) and Eq. (2), it obtain the percentage of energy transformed into heat in the drilling process of gray cast iron, Eq. (3):

$$\%P = \frac{\Delta Q}{E_{tot}} \quad [\%] \tag{3}$$

2.4. Preliminary Tests

Preliminary tests were carried out with thermocouples welded in specimen to evaluate the heat generation flow in drilling through Inverse Heat Transfer Problems. Initially, there wasn't addition of water in the calorimeter. The software used, called DPT (Determination of Thermophysical Properties), was developed in the Heat Transfer and Mass Laboratory (LTCM, acronym in Portuguese) of Federal University of Uberlandia, by PhD. Eng. Valério Luiz Borges and PhD. Eng. Gilmar Guimarães.

Thermocouples were vertically soldiers, straight, as shown in Fig. (3) and Tab. (2). For the experiments with water in the calorimeter, a further thermocouple for measuring the temperature of the water was entered. Cutting speed was 30 m/min, feed was 0.10 mm/rev and depth of the hole was 15 mm. Cutting fluid wasn't used.

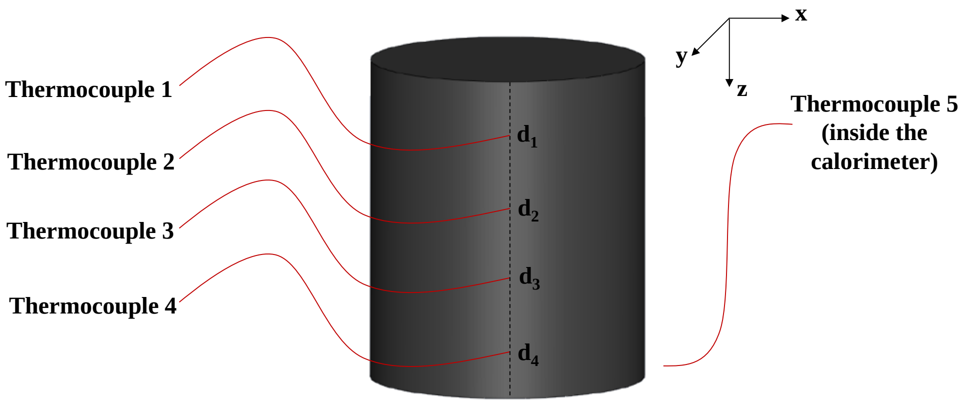

Figure 3: Position of the thermocouples on the specimen, whose distances (d_1 to d_4) were measured after welding.

Table 2: Position of thermocouples welded in specimen.

Distance (z)	Calorimeter without water (mm)	Calorimeter with water (mm)
d_1	4.60	5.30
d_2	11.18	10.14
d_3	16.20	17.36
d_4	22.40	21.84

3. RESULTS AND PRELIMINARY CONCLUSIONS

In Figure (4) and Figure (5) is shown the variations of temperatures in the specimen during machining, obtained in the experiment without water and with water in the calorimeter, respectively.

Behaviors from these preliminary experiments will be analyzed using the DPT software. Subsequently, experiments will be conducted monitoring the temperature of water, through the equations Eq. (1), Eq. (2) and Eq. (3), to determine the percentage of mechanical energy converted into heat.

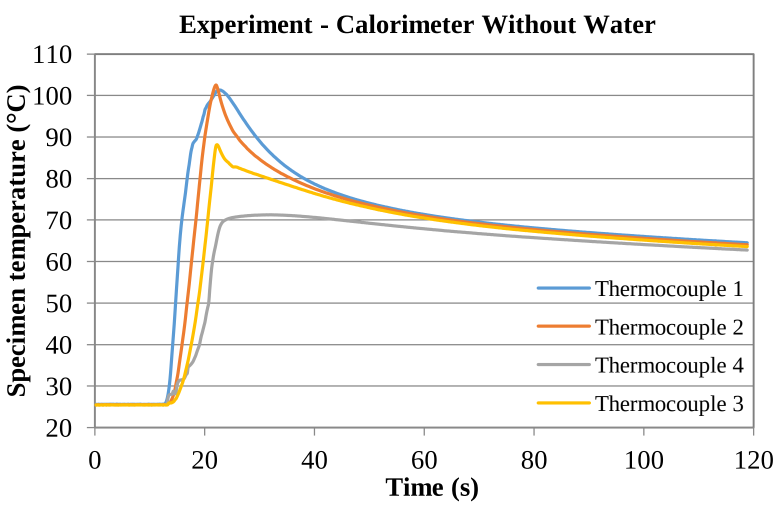

Figure 4: Temperature variation in the specimen during the experiment without water in the calorimeter.

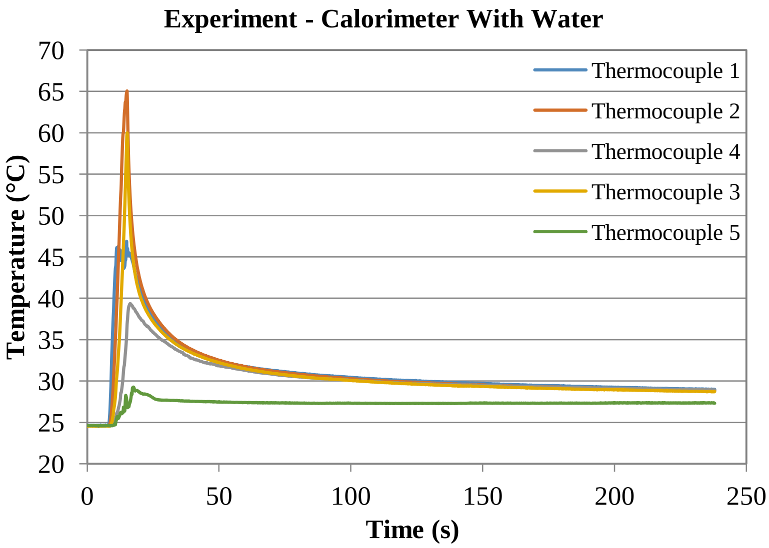

Figure 5: Temperature variation in the specimen and water during the experiment with water in the calorimeter.

Based on the results of these preliminary experiments it can be said that the calorimeter showed a consistent response and showed promise, indicating that the methodology can be used to evaluate the heat generated in gray cast iron drilling.

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6. RESPONSIBILITY NOTICE

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