MEASUREMENT OF THERMAL EMISSION DURING CUTTING OF MATERIALS USING ABRASIVE WATER JET

by

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This article deals with measurement of the thermal gradient on material during abrasive water jet cutting. The temperature was measured by thermocamera before the technological process started, during the abrasive water jet cutting process technology, and just after the cutting process. We performed measurements on several types of materials. We calculated the approximate amount of energy during the abrasive water jet cutting process technology that changes into thermoenergy, which is the current water pressure drained in a catcher tank.

Key words: *measurement, abrasive water jet, material, thermocamera*

Introduction

This paper aims to analyse the possibilities of using the accompanying physical phenomena by actively monitoring of the technological processes. In any manufacturing process derived from a principal process, accompanying physical phenomena are generated that accurately reflect the course of the technological processes [1-8]. Among the accompanying physical phenomena that are formed as part of the ongoing technological processes of cutting operations of materials, we include for example:

- the creation of light effects, abrasive water jet (AWJ) cutting of titanium [9],
- creation of vibration emission [3-5, 8],
- creation of acoustic emission [10],
- change of inductance (magnetic field) of cut material and its surroundings, and
- creation of a heat radiation [2, 11].

Specifically, we focused on the advanced technology of the cutting of materials, especially metal materials, which are cut by a high pressure AWJ. In the industrial application of this technology, we have also focused on one the accompanying physical symptoms previously listed, namely heat radiation from the place of activity of tools on the cut material. Generated thermal energy is directly dependent on the properties and characteristics of the technological process of an AWJ and on the properties of cut material, and exists only via the interaction

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thereof. Thermal energy is emitted into the environment, thus it is possible to record the emission in real time using a thermo-recorder/thermo-imager (thermocamera) [5, 6]. Captured data can then be used for further analysis during the thermal emission, and indirectly for the analysis of its own main technological process.

Problem definition

The technology of water jet and technological modifications, AWJ and pressurized water jet (PWJ), are characterized by using the forces [7, 12-14] of water flow under pressure (pressure of 20 MPa to 600 MPa) along with the homogenised inert abrasive particles of material onto the surface of cut or machined work pieces [7, 8]. The initial shape of working surface of high speed AWJ is generated in the mixing tube and depends on orifice diameter, abrasive mass flow rate, size and shape of abrasive particles. The power operation of AWJ in interaction with the cut material makes its own technological effect and functions in AWJ cutting of material. Although the abrasive particles are directed into the vector force by pressurized water, the influence of AWJ upon the cut material is stochastic. After the force action on molecules of the solid body, at the bottom of the cutting slot the abrasive particles reflect into different directions, and together with particles of the cut material they further divide the cut material. However, the particles act erratically, making thick cutting lines into the material. A large part of the AWJ force as a cutting tool is not effectively used to separate particles of cut material in the desired direction, but rather acts as a source of accompanying physical phenomena. In the case of using AWJ technology, mainly vibration emission is created [10], as well as acoustic emission and thermal emission. The heat inside cut slits of the cut material is created by the action of forces of the abrasive particles onto particles of the cut material and *vice versa* [12]. Therefore, the level of thermal emission [1] in the technological process using AWJ is directly dependent on and determined by AWJ process, *i. e.* the force action of AWJ interacting with the material which is being destroyed. This dependency and characteristics of thermal emission can be used for the indirect monitoring of the technological AWJ process in online mode, or even for the comprehensive analysis usage of data obtained with a thermo-recorder. In order to obtain relevant data on the formation and development of thermal emission during the process of cutting materials with AWJ technology, a measurement experiment was performed in pilot conditions. During the experiment, attention was paid to collecting relevant and measurable signals of various accompanying physical phenomenon, including the measurement of thermal emission, *i. e.* the formation and emission of thermal energy during the separation process of metals using AWJ technology. The picture shows a diagram of AWJ action on cut metal material. The result of the technological process of material cutting is also an accompanying physical phenomena, including the formation of thermal energy, *i. e.* thermal emission from the place of the tool's action force for cutting the material.

Experimental set-up

A manufacturing company located in Presov, Slovakia, performed/equipped with precisions devices for the cutting of metallic materials:

- aluminum plate with dimensions 250 × 120 × 30 mm and
- two-layer metal material (sandwich) consisting of the following components:
  - aluminum with thickness 30 mm and
  - structural steel AISI 309 with thickness 20 mm (dimensions 250 × 120 mm).

The temperature of the cut material before starting the experiment: 18 °C. In tab. 1 are presents the technological factors of the experiment.

Table 1. Technological factors

	Value
Pressure, p	360 MPa
Abrasive (Barton Garnet)	MESH 80
Abrasive mass flow rate, m_a	250 g/min
Focusing tube diameter, d_f	1.2 mm
Stand off, z	3 mm
Traverse speed, v_p	50 mm/s
Target material	Aluminum, AISI 309, plexiglas
Date of experiment	October 2014
Start of measurement, T_0	9.00 CET
Completion of measurement, CC	12.00 CET
Venue	DRC Company, Presov
Temperature in the hall: time, T	18 °C
Temperature in hall: time, T_z	22 °C
Water temperature in the water damper: time, T_0	18 °C
Water temperature in the water damper: time, T_Z	25 °C

Monitoring changes of surface temperature by the infrared (IR) method also requires respect for the certain simplifications and variables needed in settings of the Mobira M4 thermocamera/imager. The technical parameters of the thermocamera, in particular the amount of measured temperatures, selectivity of the sensor head, and reach – the distance measured from the work piece, were adapted and used for the purposes of this measurement [16]. The measurement methodology, the manner of measurement, the number of times sufficient to document data thermoemission before, during, and after the execution of the machining material cutting with AWJ [4]. Simplification (relative humidity in the work area is constant, set emissivity of material is given to determine material-generated images). Variable is determined by adjusting the current distance between the lenses and capturing the subject throughout the experiment. Temperature changes during the cutting of materials with current AWJ technology can be recorded on the:

- technological equipment – head,
- work piece material,
- water damper, and
- surrounding surfaces.

The subject of research is the quantification of the temperature that changes on the device head of the hydroabrasive stream and the material being processed. During the four hour measurements, an increase in temperature of 7 K and indoor air temperature of 3 K was observed due to the overheating of the water muffler. These values were, however, influenced by parameters of air from the exterior (frequent entrance door opening due to traffic). Thermal emissions (values of surface temperatures) on the device head of the hydroabrasive current are determined by several factors:

- operational device parameters (pressure, abrasive, traverse speed, *etc.*),
- shape of the head and fitted protective circular ring,
- operational length (the length of cut) and the time-gap between acts,
- splashing liquid cooling effect of water absorber,
- splashing liquid temperature,
- ambient air temperature,
- flow of ambient air, and
- radiation temperature of the work piece depending on its material composition, thickness and accumulation capabilities.

These factors (except for the last) affect the values of surface temperatures on cut material (work piece) [2].

Results and discussion

In order to determine the surface temperatures of materials that are cut by AWJ technology, a measurement was carried out under the aforementioned different conditions (changes in materials, abrasives, thickness of plates, speed of movement, cutting length). The method used was IR, non-contact determination of surface temperatures. The aforementioned variants of operational conditions created 50 thermovision images. The results of the relevant data are processed in tab. 2 and illustrated in figs. 1-5.

Table 2. Development of maximum surface temperatures of imaging for various operating conditions

Conditions of imaging – operational status			Maximum temperature, θ_{si} [°C]		
Material	Thickness [mm] / speed [mm·min^{-1}]	Time section	Head	Workpiece	Image No.
Al	20 / … 50	Before the end of operation	67.1	53.0	10
	20 / … 50	At the beginning of operation	51.4	44.9	14
	20 / … 50	Centre – 3. cut	58.2	43.0	21
	20 / … 50	At the end of 4. cut	45.4	43.3	22
Al + stainless steel	30 + … / 50	At the beginning after 10 sec	36.3	34.5	26
	30 + … / 50	End of 1. cut	58.5	43.2	27
	30 + … / 50	End of operation	60.8	44.7	30
Stainless steel + Al	30 + … / 30	Beginning of cut	54.1	32.5	34
	30 + … / 30	End of cut	61.6	47.4	35
Stainless steel + Al	30 + … / 50	Beginning of cut	59.9	38.5	38
	30 + … / 50	End of cut	52.6	44.4	39
plexi	20 / … 50	Beginning of cut	52.8	29.0	43
	20 / … 50	End of cut	61.4	40.3	44

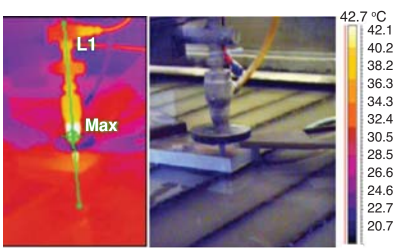

Figure 1. View of cutting Al plate of thickness 20 mm and its IR evaluation method before the end of the cutting operation – 4th cut
(*for color image see journal web site*)

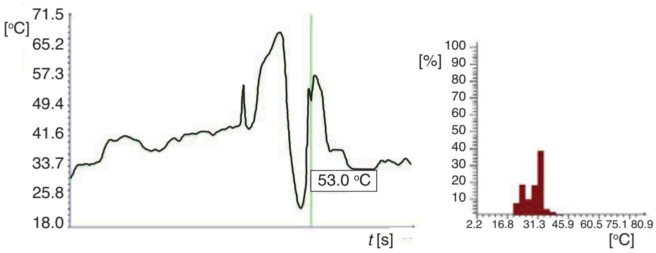

Figure 2. Development of surface temperatures and temperature histogram on the head (max. θ_{si} = 67.1 °C) and Al plate (θ_{si} = 53 °C) along the line L1 shown in fig. 1

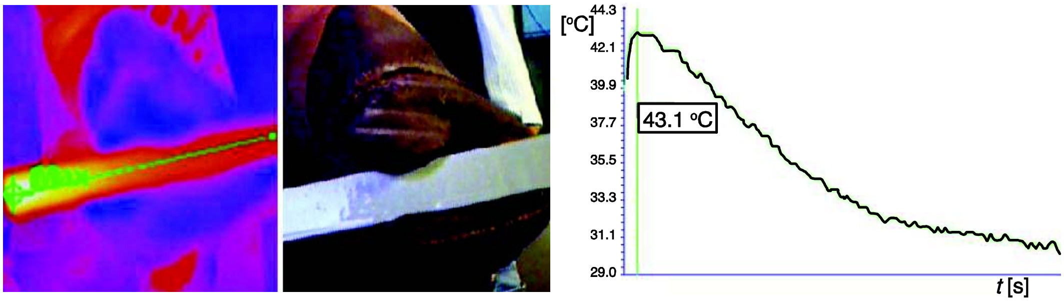

Figure 3. Detail of the separated Al plate of thickness of 20 mm and the development of surface temperatures

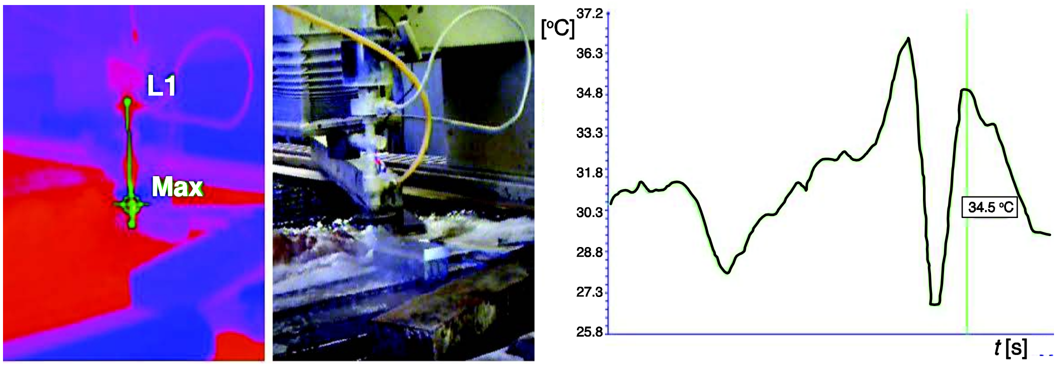

Figure 4. View of cutting Al plate + stainless steel in a sandwich configuration and evaluation of its IR method at the beginning of operation and development of temperatures

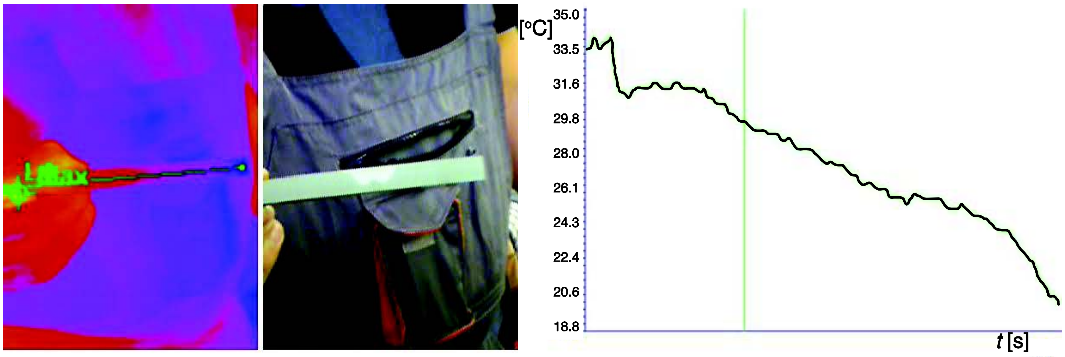

Figure 5. Detail of a plexiglas plate of thickness 20 mm and development of surface temperatures

During the actual performance of technological cutting of material by AWJ, cut material is heated only slightly. The increase in temperature on the material during the process was measured in the range of 25°C to 35°C compared to the status before technological process began. The performed technological process lasted about 3-5 min per piece cut material.

The temperature rise was caused by converting the kinetic energy of the abrasive particles incident on the surface of the cut material. Part of this energy is converted into heat energy, which is cut by the heated material. The majority of the thermal energy, however, is continuously discharged PWJ. The working tool, AWJ, also works as a coolant, which protects against unwanted material cut by overheating during the performance of the technological process.

The results of the assessment of materials surface temperatures indicate that AWJ technology in cutting materials does not affect the physical and chemical properties thereof. The measured temperatures of material, which in the course of the technological process did not exceed 60 °C, thus do not attain the levels of temperature at which at least minor changes occur in the structure of the material. Therefore, the use of hydroabrasive jet technology does not affect the mechanical especially strength-parameters of cut materials, particularly metals.

Calculation of the amount of energy delivered through AWJ to the destination surface AWJ cut material. The kinetic energy of the moving body:

$$E_c = \frac{mv^2}{2}$$

The energy imparted to a surface by the action of AWJ per unit of time is $m_{\mathrm{fr}} v_{\mathrm{f}}^2 / 2$, where m_{fr} is the abrasive mass flow rate = 250 gmin^{-1} = 4.11 gs^{-1} and v_{f} – the exit velocity of abrasive particles upon exiting the technological head, if necessary upon impact on the cut material's surface.

We assume that v_{f} = 450 ms^{-1} (at an altitude of 290 m above sea level, which is the altitude of the experiment location, Presov, Slovakia), so $E_{\mathrm{cs}} = m_{\mathrm{fr}} v_{\mathrm{f}}^2 / 2$ is the amount of energy delivered to the surface by the action of AWJ per second and can be calculated:

E_{cs} = 4.11 gs^{-1}·(450 ms^{-1})^2/2 = 4.11 gs^{-1} · 202500 m^{2}s^{-2} / 2 = 416.137 Js^{-1}

Conclusions

The analysis of thermo-imaging can include the following results.

- The maximum surface temperature of the device in the system – environment – material (work piece) is on the device header.
- Material temperature on Al plate of thickness 20 mm ranged from 43.0 °C to 53.0 °C, limiting temperature of the material deformation is 250 °C.
- Material temperature on Al + stainless steel (of thickness 30 mm) board ranged from 34.5 °C to 44.7 °C, limiting temperature of the material deformation is 280 °C.
- Material temperature for stainless steel (of thickness 30 mm) board ranged from 32.5 °C to 47.4 °C, limiting temperature deformation of the material is 400 °C.
- Temperature material on plexiglass plate (of thickness 20 mm) ranged from 29.0 °C to 40.3 °C, limiting temperature of deformation of the material is 80°C.
- The majority of initial kinetic energy during the technological process changed into heat energy. Thermal energy was drained degraded material and the reflected particles in the water muffler. The water will absorb the entire volume of the residual kinetic energy of the particle material and the dissipating amount of thermal energy.

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