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

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Original Scientific Paper

*This article deals with measurement of the thermal gradient on material during abrasive water jet cutting. The temperature was measured by thermo camera before the technological process started, during the AWJ 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 AWJ cutting process technology that changes into thermo energy, 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 (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,
- creation of a heat radiation [2, 12].

Specifically, we focused on the advanced technology of the cutting of materials, especially metal materials, which are cut by a high pressure abrasive water jet. In the industrial application of this technology, we have also focused on one the accompanying physical symptoms listed above, 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 abrasive water jet and on the properties of

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cut material, and exists only via the interaction 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 (thermo camera) [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, PWJ) are characterized by using the forces [7, 13, 14, 16] 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's 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's 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 [15]. 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 phenomena, 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's 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 performed/equipped with precisions devices for the cutting of metallic materials:

1. Aluminium plate with dimensions 250 mm × 120 mm × 30 mm,
2. Two-layer metal material (sandwich) consisting of the following components:
  - a. Aluminium with thickness 30 mm,

- b. Structural steel AISI 309 with thickness 20 mm (dimensions 250 mm × 120 mm)

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

**Table 1. Technological factors.**

	Value
Pressure $p$	360 MPa
Abrasive (Barton Garnet)	MESH 80
Abrasive mass flow rate $m_a$	250 g·min <sup>-1</sup>
Focusing tube diameter $d_f$	1.2 mm
Stand off $z$	3 mm
Traverse speed $v_p$	50 mm·s <sup>-1</sup>
Target material	Aluminium, AISI 309, Plexiglas
Date of experiment	October 2014
Start of measurement $T_0$	9.00CET
Completion of measurement $CC$	12.00CET
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 method also requires respect for the certain simplifications and variables needed in settings of the Mobira M4 thermo camera-imager. The technical parameters of the thermo camera, 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 [6]. The measurement methodology, the manner of measurement, the number of times sufficient to document data thermo emission 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 lens 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,
- surrounding surfaces.

The subject of research is the quantification of the temperature that changes on the device head of the Hydro abrasive 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 Hydro abrasive 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,
- 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 above-mentioned different conditions (changes in materials, abrasives, thickness of plates, speed of movement, cutting length). The method used was the infrared, non-contact determination of surface temperatures. The above-mentioned variants of operational conditions created 50 thermo vision images. The results of the relevant data are processed in Table 2 and illustrated in Figs 1-5.

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

Material	Conditions of imaging – operational status		Maximum temperature $\theta_{si}$ [°C]		
	Thickness [mm] / speed [mm·min <sup>-1</sup> ]	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 seconds	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

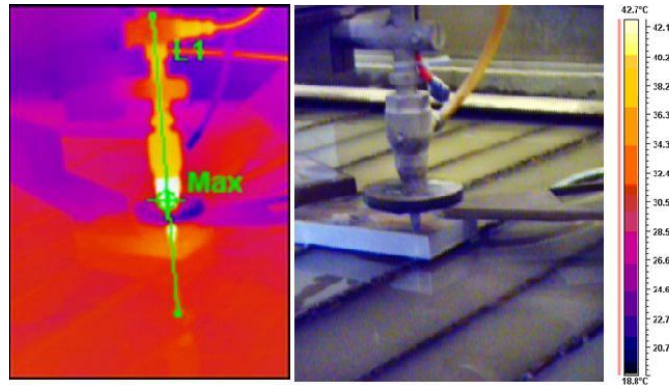


Figure 1. View of cutting aluminium plate of thickness 20 mm (image 10) and its infrared evaluation method before the end of the cutting operation – 4<sup>th</sup> cut.

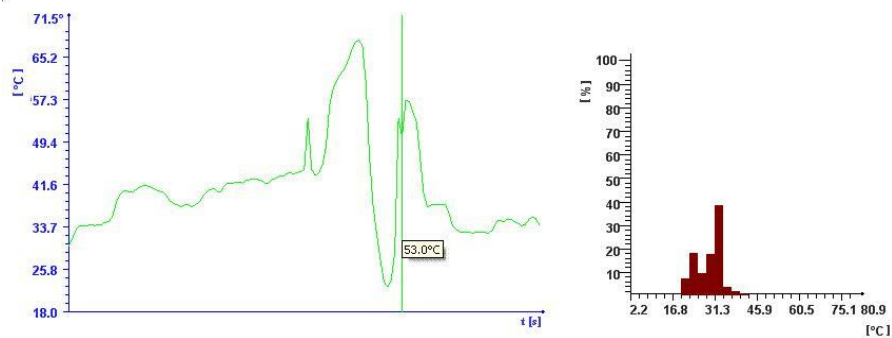


Figure 2. Development of surface temperatures and temperature histogram on the head (max.  $\theta_{si} = 67.1$  °C) and aluminium plate ( $\theta_{si} = 53.0$ °C) along the line L1 shown in figure 1.

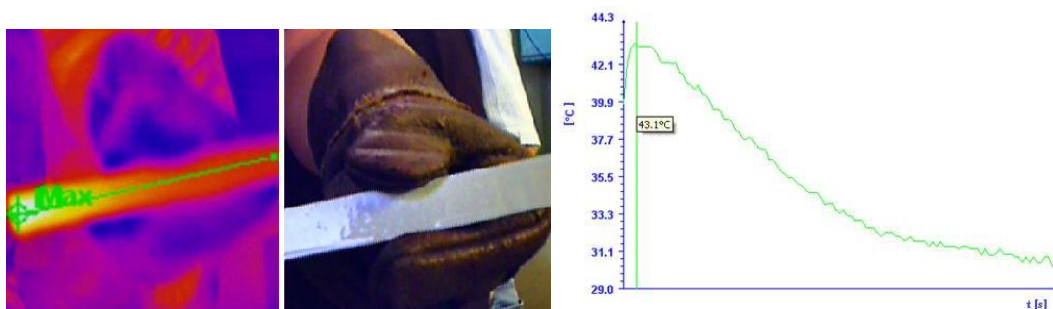
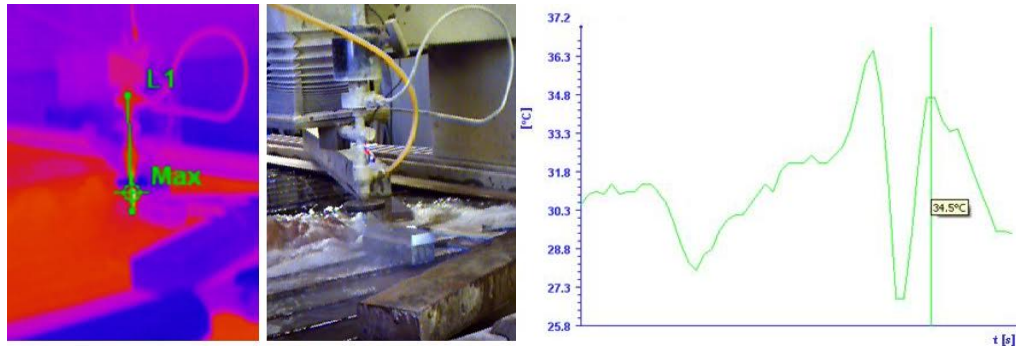
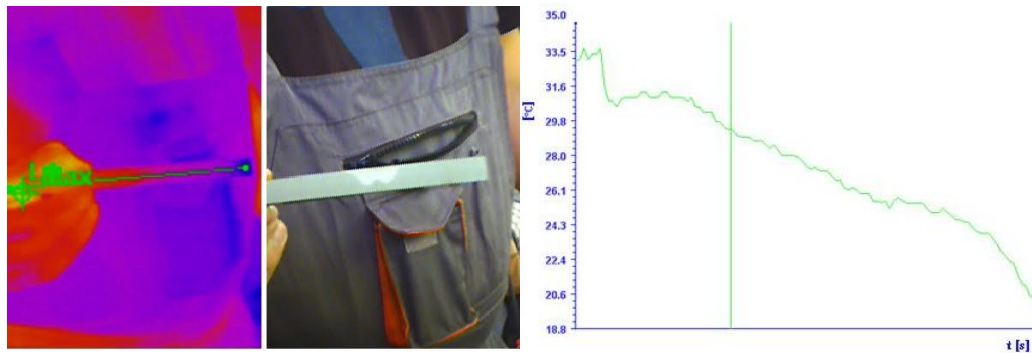


Figure 3. Detail of the separated Al plate of thickness of 20 mm and the development of surface temperatures.



**Figure 4.** View of cutting aluminium plate + stainless steel in a sandwich configuration and evaluation of its infrared 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/ 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 pressurized water - water jet. 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 hydro abrasive 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:

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$$E_c = m \cdot v^2 \cdot 2^{-1}$$

The energy imparted to a surface by the action of AWJ per unit of time =  $m_{fr} \cdot v_f^2 \cdot 2^{-1}$ ,  $m_{fr}$  = abrasive mass flow rate =  $250 \text{ g} \cdot \text{min}^{-1} = 4.11 \text{ g} \cdot \text{s}^{-1}$ ,  $v_f$  = exit velocity of abrasive particles upon exiting the technological head, if necessary upon impact on the cut material's surface.

We assume that  $v_f = 450 \text{ m} \cdot \text{s}^{-1}$  (at an altitude of 290 m above sea level, which is the altitude of the experiment location, Prešov, Slovakia), so  $E_{cs} = m_{fr} \cdot v_f^2 \cdot 2^{-1}$  = the amount of energy delivered to the surface by the action of AWJ per second, can be calculated as follows:

$$E_{cs} = 4.11 \text{ g} \cdot \text{s}^{-1} \cdot (450 \text{ m} \cdot \text{s}^{-1})^2 \cdot 2^{-1} = 4.11 \text{ g} \cdot \text{s}^{-1} \cdot 202500 \text{ m}^2 \cdot \text{s}^{-2} \cdot 2^{-1} = 416.137 \text{ Joule} \cdot \text{s}^{-1}$$

## 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 – 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 – 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 – 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 – 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.

## Acknowledgement

This work was supported by the Slovak Research and Development Agency under contract no. APVV-207-12.

## References

- [1] Simko, M., Chupac, M., Thermovision in praxis, University of Zilina, Zilina, SK, 2007
- [2] Kovacevic, R., Mohan R., Beardsley H. E., Monitoring of thermal energy distribution in abrasive waterjet cutting using infrared thermography, *J. Manufact. Sci. Eng.*, 118 (1996), pp. 555-563
- [3] Hreha, P., et al., Monitoring of focusing tube wear during Abrasive WaterJet (AWJ) cutting of AISI 309, *Metalurgija*, 53 (2014), 4, pp. 533-536
- [4] Hreha, P., et al., Investigation of sandwich material surface created by abrasive water jet (AWJ) via vibration emission, *Metalurgija*, 53(2014), 1, pp. 29-32
- [5] Hreha P., et al. Roughness parameters calculation by means on-line vibration monitoring emerging from AWJ interaction with material, *Metrology and Measurement Systems*, XXII (2015), 2, pp. 315 – 326

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- [6] Hlaváček, P., et al. Sandstone turning by abrasive water jet, *Rock Mechanics and Rock Engineering*, 48 (2015), 6, pp. 2489-2493
- [7] Zelenak, M., et al. Visualisation and measurement of high-speed pulsating and continuous water jets, *Measurement*, 72 (2015), pp. 1-8
- [8] Kinik, D., et al. On-line monitoring of technological process of material abrasive water jet cutting, *Tehnicki Vjesnik*, 22 (2015), 2, pp. 351-357
- [9] Hloch, S., et al. Abrasive water jet (AWJ) titanium tangential turning evaluation, *Metalurgija*, 53 (2014), 4, pp. 537-540
- [10] Hloch, S., et al. Analysis of acoustic emission emerging during hydroabrasive cutting and options for indirect quality control, *Int. J. Man Tech.*, 66 (2013), 1-4, pp. 45-58
- [11] STN EN 13187 Thermal performance of buildings. Qualitative detection of thermal irregularities in building envelopes. Infrared method.
- [12] Brown, S., Thermal emission measurement and calibration, Bachelor thesis, Massachusetts Institute of Technology, Massachusetts, USA, 2009
- [13] Foldyna, J., et al., Utilization of ultrasounds to enhance high-speed water jet effects, *Ultrasound Sonochemistry*, 11 (2004), 3-4, pp. 131-137
- [14] Foldyna, J., et al., Erosion of metals by pulsating water jet, *Technicki vjesnik*, 19 (2012), 2, pp.381-386
- [15] Hreha, P., et al., Determination of vibration frequency depending on abrasive mass flow rate during abrasive water jet cutting, *Int. J. Man Tech.*, 77 (2014), 1, pp. 763-774
- [16] Hloch, S., et al., Disintegration of bone cement by continuous and pulsating water jet, *Technicki vjesnik*, 20 (2013), 4, pp. 593-598

Paper submitted: 02.02.2015

Paper revised: 31.07.2015

Paper accepted: 29.01.2016