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Temperature measurement in the bundle of metal sheets being cut on a guillotine with respect to heating process

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ABSTRACT

Purpose: The work was aimed at temperature measurement with respect to the heating process in the bundles of metal sheets in the direct cutting zone during the cutting process conducted on a guillotine.

Design/methodology/approach: The paper presents a methodology to analyse the process of heating the bundles of metal sheets during cutting on a guillotine, designed and built from scratch. The temperature in bundles in the direct cutting zone has been determined in an experimental way using a specialised infrared camera. The research has been conducted in order to reduce the number of randomly occurring defects during cutting of metal sheets on a guillotine.

Findings: Possibilities of finding of the optimum cutting parameters on account of maximum permissible temperature in the bundles of metal sheets have been determined. The experimental data indicates that it is possible to select a set of guillotine parameters which allow for reducing of temperature measured in the direct cutting zone. Temperature reduction allows for avoidance of defects which might occur in the direct cutting zone as the result of progressing heat transfer during cutting. The defects occurring on the blade of a cutting tool might also contribute to the local growth of temperature corresponding to the positions of the defects on the blade.

Research limitations/implications: The experimentally assumed characteristics of temperature versus time for in advance chosen cutting parameters may be generalized for a wide gamut of materials and for changeable cutting conditions; however, the obtained experimentally values of temperature are specific and related to the chosen types of materials and fixed cutting conditions of a guillotine.

Practical implications: The appropriate selection of the cutting parameters on account of temperature characteristics is essential in terms of industrial economy. It enables reducing the amount of waste caused by defects in cutting bundles of sheets and decreases wear of the cutting tool.

Originality/value: The results acquired from the research form a base for selection of the best parameter settings required for conducting the optimum cutting process on a guillotine. The optimum set of cutting parameters combined with the lowest possible value of temperature generated in the direct cutting zone leads to the reduction of defects' number occurring during the process.

Keywords: Infrared imaging camera; Direct cutting zone; Heat flow; Defects

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1. Introduction

The cutting process often leads to the occurrence of random defects at the blade's tip of a cutting tool and consequently can cause the formation of defects in bundles of sheets being cut. Defects on the cutting tool are usually generated by imperfections in the internal structure of the cutting tool material, large values of stresses during the cutting process, the progressive degradation of mechanical properties and the decreasing fatigue strength of a cutting tool. Impropriate selection of cutting parameters can cause the formation of additional defects in the shape of built-up edges on a cutting tool, the most commonly occurring since too low cutting velocity. Additionally, local high hardness of cutting material can make dents in the cutting tool blade. Regular sharpening of a cutting tool substantially reduces the frequency of defects arising. The occurrence of defects in the cut material is due to the presence of defects on the blade of a cutting tool. In the process of defects' creation either in the blade of a cutting tool or in the cut material, the local heat fluxes are generated and subsequently they contribute to a local increase in temperature [15-19]. Disorders in the internal structure of the cut material in the form of non-metallic inclusions or imperfections in the crystalline structure of metals are also a cause of defects' generation [22]. Another cause of defects in the cut material is coating of the external surface of metal sheets with protective layers for special purposes such as light-sensitive which are generally characterized by a much greater hardness compared to the sheets without additional coating. Therefore, there is an increased probability that the hard material particles of coating stick to the blade of a cutting tool and in next cutting cycle, these particles cause the formation of vertical craters in the cut material [2, 4]. The frequency of defects arising can be minimized by selecting the optimum cutting process parameters by using modern measurement techniques such as measuring the temperature distribution in the direct cutting zone applying a thermal imaging camera.

At present guillotines are more frequently used in industry for cutting bundles of metal sheets taking into account their high efficiency in a cutting process in comparison to the cutting efficiency of single sheets on guillotine shears. However, as it has already been mentioned, it frequently happens that random undesirable defects occur in bundles' cross-section, subsequently guillotines use more energy, a cutting tool of the guillotine becomes blunt more quickly, more heat is emitted in the cutting process, consequently the machines undergo the extended wear and provide a large amount of waste, which is directly linked to increased expenses incurred on production. The temperature growth of the bundles during cutting comes out from friction, plastic deformation etc. Depending on temperature, the mechanical properties of metal sheets as well as the properties of coated protective layers on the sheets' surfaces deteriorate in the direct cutting zone and therefore it seems necessary to optimise the parameters of an unsteady heat flow [1-4, 20, 21].

In this paper, the determination of temperature in the direct cutting zone in an experimental way is presented. The specialised infrared camera *FLIR SC655* with the lens 25º was used during the investigation. It facilitates the analysis of temperature in the direct cutting zone concerning the designation of the maximum temperature values versus time during cutting the bundles of sheets. Before the measurement of temperature in the cutting zone, the outer surfaces of the bundles were painted with special heavily mat spray. This allowed for the elimination of the sources of energy reflected by the bundle and enabled more accurate measurement of temperature in the cutting region. In the initial phase of cutting the bundles, the elastic region appears and gradually the material gains plasticity, and then it strengthens and fractures with simultaneous arising of friction between the cut surfaces of metal sheets and a cutting tool [2,4,9,10]. The described physical phenomena are responsible for generating the heat flux [1,3]. The temperature measurement consisted in visualization of the cutting process in the infrared wavelength range from about 0.9 to 14 μm. This allowed the registration of the thermal radiation emitted by the outer surfaces of the bundles in the direct cutting zone, without the need for external illumination by a light source. The cutting process of metal sheets on guillotines is characterized by short duration (about 0.3 s). During this time, the metal sheets are being heated as a result of their separation and temperature peaks occur. The peaks are quite sharp, which means that the temperature soars rapidly in the direct cutting zone, and then plummets due to high thermal conductivity of metal sheets and heat dissipation to the surroundings by convection and radiation [6,7,8]. The influence of different parameters of a guillotine such as: thickness of single sheets in the bundle, cutting velocity and force loading the pressure beam on the maximum temperature values in the direct cutting zone, has been established.

2. Description of the experimental stand

The prototypical stand for cutting is characterised by a possibility of cutting at an arbitrary angle within a range from 30º to 90º relatively to the horizontal work top of a guillotine in distinction from traditional machines which operate at a certain fixed angle, generally used in industry. The functioning of the guillotine is based on a slider-crank mechanism joined with an electrical power transmission system whose task is to produce a constant value of a linear velocity of the blade of a cutting tool in the process (Fig. 1).

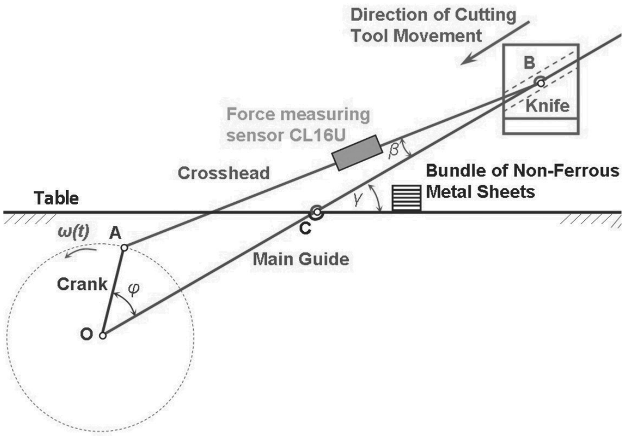

Fig. 1. Scheme of a prototypical guillotine

This guillotine is equipped with a power transmission system comprising a servomotor integrated with a helical gearbox, an inverter and software enabling the controlling of an angular velocity at the output of a helical gearbox. The applied servomotor allows the guillotine to work with a variable angular velocity at the output of a helical gearbox (Fig. 3) in such a way that the blade of a cutting tool moves with a constant value of a linear velocity (Fig. 2).

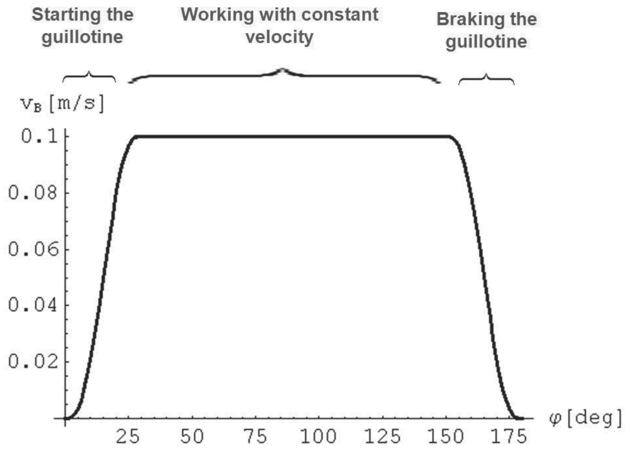

Fig. 2. Combination of three functions of velocities of the cutting tool versus an angle

The applied servomotor makes possible to compare the surface quality of the cut sheets in a bundle. It allows for controlling the velocity and ensures a constant speed of the blade of a cutting tool during the process using *L-force Engineer* computer system. This software controls the motor's speed on the basis of characteristics describing the relationship of an angular path at the output of a helical gearbox versus time. To designate the above mentioned characteristics, an author's computer program using the object oriented language C++ was elaborated. The electrical power transmission system was combined with the mechanical module of a prototypical guillotine. The servomotor drives a helical gearbox which in turn drives the crank mechanism with an adjustable length of the eccentric through a rigid safety clutch. The crank was joined to a crosshead with an adjustable length depending on a slope of a main guide relatively to the horizontal work top of a guillotine's table. The other end of the crosshead is linked to a sliding block where the blade of a cutting tool moves parallel to the main guide (Fig. 1).

An angular velocity versus an angular displacement embraces three stages required for a single working cycle of the machine. The first stage concerns starting the machine; in this stage a linear velocity of the cutting tool was described by a polynomial of fifth degree in order to attenuate the dynamic forces. The second stage is tied to the realisation of the cutting process with a constant velocity of the cutting tool, and the third stage concerns the servomotor braking. In the last stage as in the first one, a velocity of the cutting tool was also described by a polynomial of fifth degree. The servomotor rotates with a variable angular velocity whose hypothetical values at the output of a gearbox versus an angular displacement were presented in Fig. 3 [5].

Cutting forces have been also measured by means of a sensor CL16U mounted on the crosshead (Fig. 1) [11].

Many scientists investigated machining processes. On the basis of the research investigations can be stated that in the direct machining zone either forces or temperatures violently change [9-12] leading to the destruction of material. This process is based on complex interconnected phenomena and in general would be described using different kind of phenomenological models [13,14]. The destruction mechanisms might be applied to the analysis of the cutting processes.

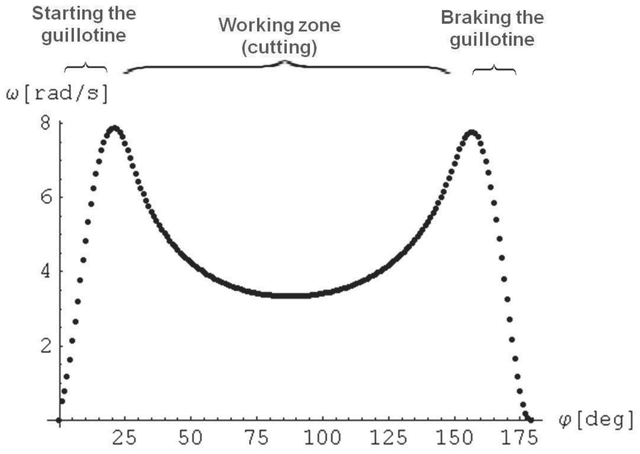

Fig. 3. An angular velocity versus an angular displacement at the output of a gearbox

Experimental investigations were carried out using a specialised *FLIR SC655 thermal imaging camera* with a frequency of 200 thermo-graphic frames per second (Fig. 4). It was linked via an *Ethernet* connection to a portable computer equipped with professional software *ThermaCAM Researcher Pro 2.10* (Fig. 5) for the analysis of thermo-graphic films and images. This computer program allows for communication with the infrared camera, enables the video and photo processing as well as makes easier the preparation of thermo-graphic courses of temperature as a function of time with pre-defined zones marked on the film.

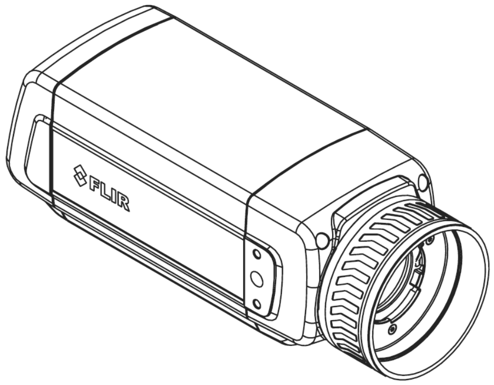

Fig. 4. Thermal imaging camera *FLIR SC655*

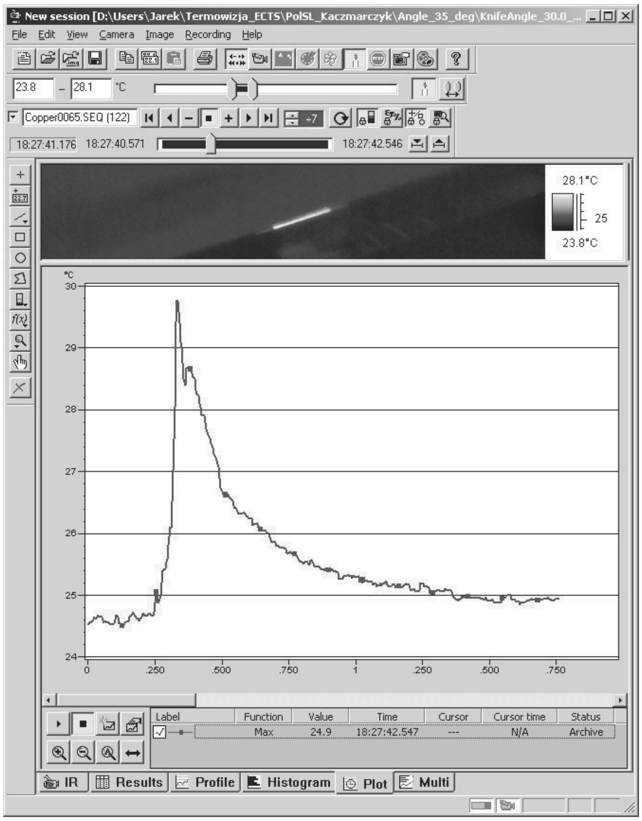

Fig. 5. Computer program *ThermaCAM Researcher Pro 2.10*

The scheme of the cutting process is shown in Fig. 6. On the working surface of the guillotine's table, metal sheets were arranged in a bundle and next loaded by means of the pressure beam.

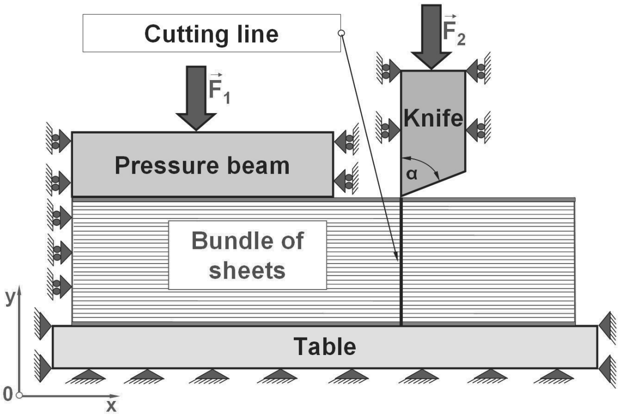

Fig. 6. Scheme of the cutting process of sheets arranged in a bundle

Observation of the temperature field in the direct cutting zone was possible in the initial stage when the knife cuts through the first sheet from the top of the bundle. During cutting the next sheet, the blade of a cutting tool penetrates into the bundle at such a depth that the thermovision camera is no longer able to track changes in temperature, up to the last sheet being cut. Placing the camera on the other side, or observation of the cutting process from the front of the bundle is hindered by the fact that the view is obscured by a vice, which is used to pre-load the bundle.

3. Experimental determination of temperature in the cutting zone

The research concerning the designation of temperature curves was conducted for copper specimens depending on various parameters of the cutting process, such as:

- force loading the pressure beam,
- cutting velocity understood as the velocity of the movement of a cutting tool, thickness of an individual sheet in the bundle.

The experiment was carried out at an ambient temperature of about 23°C. In Fig. 7 the selected course of the maximum temperature values versus time in the direct cutting zone is presented.

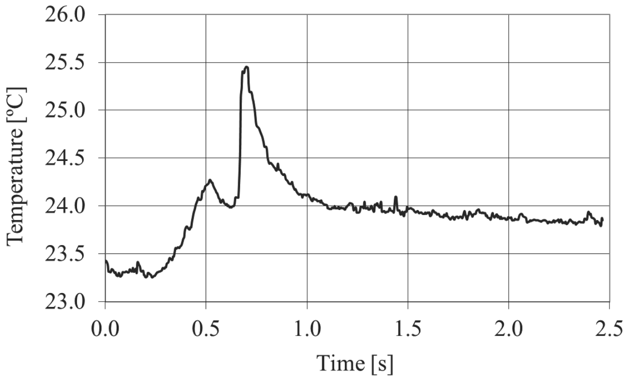

Fig. 7. The selected graph of a course of the maximum temperature values versus time for the established value of cutting velocity

In the initial stage of measurements, the ambient temperature was registered. The instant at which the temperature begins to increase corresponds to the knife blade contact with the top sheet of the bundle. Then, the temperature rapidly increases up to a maximum value and next decreases rapidly forming a characteristic peak. It results from progressive deformation of the metal sheets bundle under influence of the force exerted by the blade of a knife. The peak formation begins at the moment when the blade touches the metal sheet. Initially, the elastic deformation occurs, in the later stage, the material begins to plasticise up to the moment when the ultimate strength is exceeded and the sheet being cut starts to crack. This process is accompanied for the whole time by the friction occurring between the surfaces of the material being cut and the knife. At the moment of rupture of the material along the cutting line, the metallic bonds break and the cutting force simultaneously decreases until the knife comes into contact with another sheet of the bundle. The drop in temperature shown in the graph is associated with weakening of the cutting force. In the final stage of the graph, the establishing temperature is slightly higher than the ambient temperature, due to the increase of internal energy of the material in the result of the heat absorption generated by cutting process. The cutting process is highly dynamic and of short duration (lasts about 0.3 s). The rapid increase and decrease in temperature is associated with high thermal conductivity of copper.

In Fig. 8 the curves of courses of temperature versus time for three forces loading the pressure beam, arranged in ascending order are juxtaposed. These forces are caused by a torque of tightening the bolt loading the pressure beam using a specialized torque wrench. A torque of 0 N·m corresponds to low values of force (approximately equal to 0 N) loading the bundle of sheets. The presented graph shows that with increasing force loading the pressure beam, the maximum peak values of temperature decrease. This is due to decreasing of maximum values of force measured on the knife during the cutting process. This phenomenon can be explained by the growth of pre-stress in bundles of sheets caused by the increasing loading of the pressure beam. It is easier to cut a metal sheet with introduced pre-stress in comparison with cutting a metal sheet without pre-stress introduced, in a certain fixed loading range.

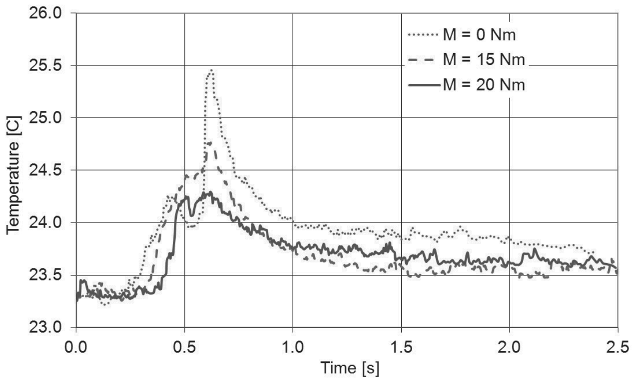

Fig. 8. Comparison of experimental courses of temperature versus time according to force loading the pressure beam which corresponding to the given tightening torque (M)

In Fig. 9 the curves of courses of temperature versus time for three cutting velocities, arranged in ascending order are juxtaposed. These velocities correspond to the given frequencies. To drive the prototypical guillotine, a servomotor along with a gearbox was applied. This solution enabled the realization of a prototypical guillotine drive with a possibility to set a required velocity in a stepless way within a limited range from 0.01 to 0.1 m/s on the cutting tool [5]. The presented graph shows that with increasing linear velocity of the blade of a cutting tool, the maximum peak values of temperature also rise. This is due to increasing dynamics of the cutting process. It can also be explained by increasing maximum values of force measured during the cutting process according to the increasing velocity of a cutting tool.

In Fig. 10 the curves of courses of temperature versus time for three different thicknesses of an individual sheet in the bundle, arranged in ascending order are juxtaposed. The presented graph shows that with increasing thickness of a sheet in the bundle, the maximum peak values of temperature also rise. This is due to increasing stiffness of metal sheets in the bundle, which characterises the capability of metal sheets to resist the cutting force. This can also be explained by increasing maximum values of force measured during the cutting process according to the increasing thickness of sheets in the bundle.

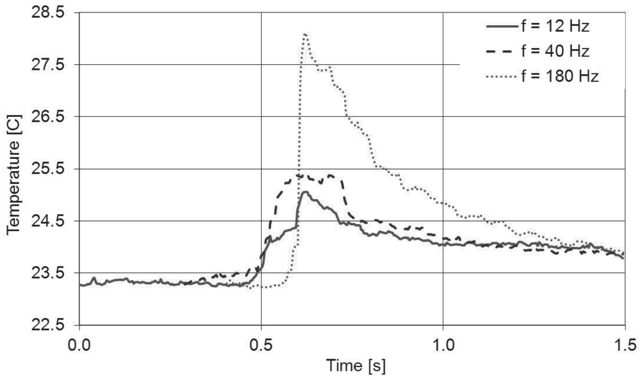

Fig. 9. Comparison of experimental courses of temperature versus time according to velocity of the cutting tool corresponding to the given cutting frequency (f)

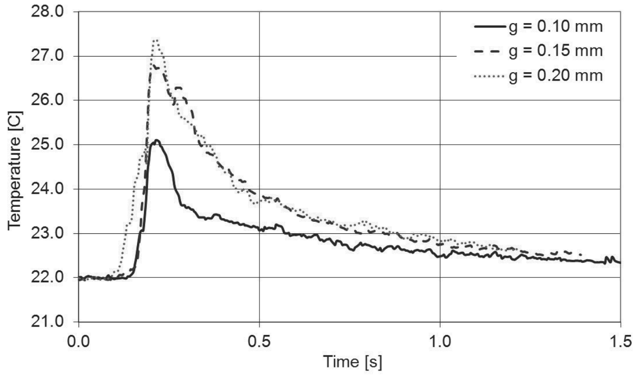

Fig. 10. Comparison of experimental courses of temperature versus time according to the thickness of a single metal sheet in the bundle

4. Conclusions

- In the direct cutting zone temperature values might influence on local mechanical properties of the cutting material in a significant way.
- Increasing the force loading the pressure beam within an investigation range (0 to 20 N·m) decreases the maximum values of temperature in the direct cutting zone.

- Increasing the cutting velocity of the blade increases the maximum values of temperature in the direct cutting zone.
- Increasing the thickness of a single metal sheet in the bundle increases the maximum values of temperature in the direct cutting zone.
- Defects arising during cutting the bundles of sheets cause an increase in cutting force and a local rise locally in temperature.
- The uneven growth in temperature in a bundle, along the edge of the blade during cutting allows detecting places where defects on the blade might arise.
- The presented methodology concerning the relationship of the local temperature rising in a bundle with the occurrence of a defect on the blade allows for the early detection of defects and facilitates an assessment of the cutting tool wear.

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