

## Investigation of Temperature Distribution during Milling Process of Az91hp Magnesium Alloys

Piotr ZGÓRNIAK  
Anna GRDULSKA

*Institute of Machine Tools  
and Production Engineering  
Technical University of Łódź  
piotr.zgorniak@p.lodz.pl  
anna.grdulska@p.lodz.pl*

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The present paper deals with temperature distribution into cutting zone during end milling operation of magnesium alloy AZ91HP. The quality of the items is closely related to the state of the surface layer. High temperature generated during cutting process may cause risk of chips ignition when magnesium alloys is subjected to cutting process. Unfavorable phenomena such as the loss of hardness and cutting ability of the cutting tool. In recent years application of thermal imaging technique for monitoring material removal processes has dramatically increased. To determine influence of cutting velocity on maximum temperature appeared during end milling process infrared measurements were conducted. Results and conclusions is presented in the paper.

*Keywords:* Infrared temperature measurement, material removal, end-milling, Titanium alloy, Magnesium alloy.

### 1. Introduction

Since the goal of any material removal processes is the component that consistently meets specifications. To improve the quality of the finished workpiece it is essential to know temperature distribution into the cutting zone. Furthermore, studies have shown that in material removal processes, phenomena that can degrade workpiece quality is strictly connected with temperature history of the workpiece [1]. Milling operation is one of the most popular removal process employed in aerospace and automotive industries. In many cases parts are made of magnesium alloys to reduce mass and ensure satisfactory mechanical and heat resistant properties [2]. However cutting these types of materials without careful selection of cutting parameters can cause chips ignition [3]. On the other hand application of "safer" cutting parameters may be economically unjustified. For these reasons knowledge about temperature

distribution into cutting zone is essential for safety reasons and efficiency of cutting operations concerning magnesium alloys [4]. However, the measurement of cutting temperatures in milling process presents unique technical challenges connected with complex kinematics and disturbing sources (e.g. different emissivity coefficients for tool-workpiece interface, rotated cutting tool, environment conditions, disturbance from different heat sources etc.) [5, 6, 7].

## 2. Workpiece material

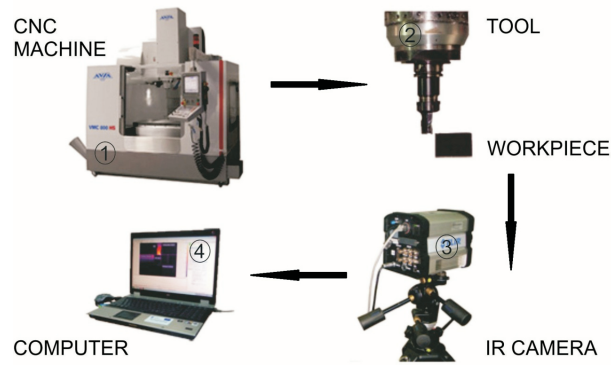
During investigation AZ91 HP magnesium alloy workpiece material have been selected. Chemical composition of workpiece material has been presented in Tab. 1.

**Table 1** Chemical composition of magnesium alloy AZ91HP – [PN-EN 1753:2001]

Cu	Mn	Mg	Zn	Si	Fe	Al	Ni
0,016	0,17	rest	0,72	0,03	0,002	9,45	0,025

## 3. Machining arrangement

Investigations were carried out by means of experimental stand presented in Fig. 1.



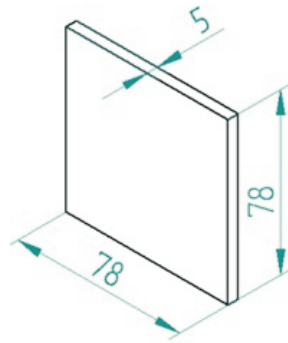
**Figure 1** Experimental arrangement for IR cutting tests

The cutting was carried out on a CNC vertical machining center VMC800HS (1). Close-up of CNC machine's workspace (2) presents tool-workpiece interface. Samples were prepared as cuboidal in shape. They were made of the magnesium alloy AZ91HP painted with matt black color. Milling processes were conducted by means of end milling cutter R216.33-16030-AC26P 1630 from Sandvik Coromant which is presented in Fig. 2.



**Figure 2** The end milling cutter R216.33–16030–AC26P 1630 from Sandvik Coromant Corporation

Measurement of the temperature distribution in milling of magnesium alloy was performed on cuboid samples with dimensions 78x78x5 [mm]. Schematic view of the samples is presented in Fig. 3.



**Figure 3** Schematic view of the sample used during cutting tests

In order to provide repeatable conditions during cutting process, the samples were made of the same size to ensure the equal volume removed from the workpiece during each test. To get proper temperature values during cutting tests it was necessary to determine the emissivity of the workpiece material. Therefore the samples made from magnesium alloy were painted with matt black color of known emissivity coefficient equal to 0.94.

During the milling process, the temperature distribution of the workpiece and the maximum temperature values were recorded by infrared camera FLIR SC6000HS presented in Fig.1 position (3). Technical parameters of IR camera applied during cutting test are presented in Tab. 3.

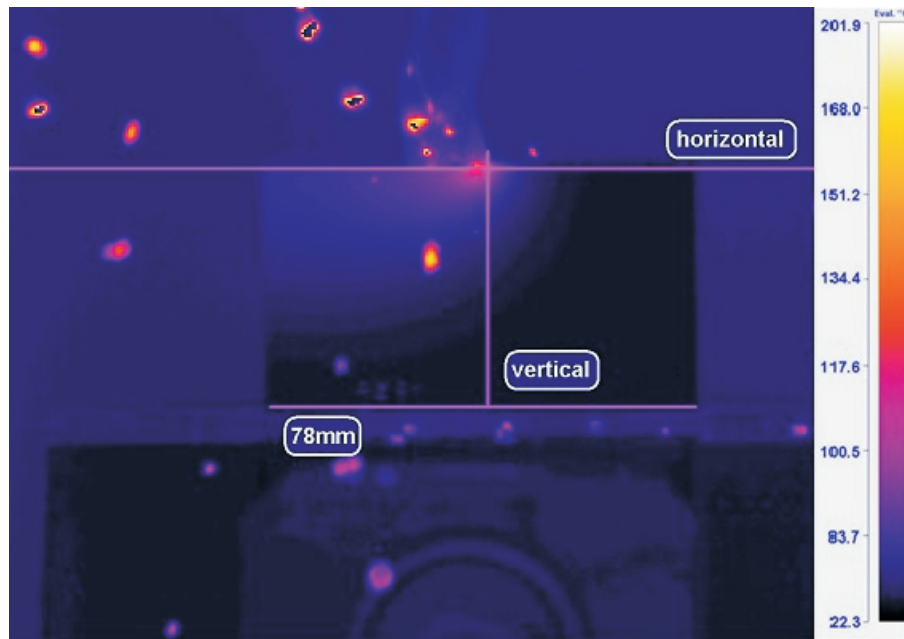
The last element of the measuring arrangement is the computer (Fig. 1 position 4) equipped with special software IR control which enable to record thermal data for future evaluation.

**Table 2** Technical parameters of IR camera applied during cutting

Detector Specification	
Detector	InSb
Spectral range	3-5 [ $\mu\text{m}$ ]
Resolution	640 x 512
Pixel Pitch	30 x 30

#### 4. Experimental method

Investigation concerned evaluation of cutting velocity influence on maximum temperature into cutting zone. On the base of line analysis tool located horizontally at the intersection of end-mill cutter and the workpiece material, maximum temperatures were recorded in each frame of IR sequences. The view of the IR control graphical interface is shown in Fig. 4.

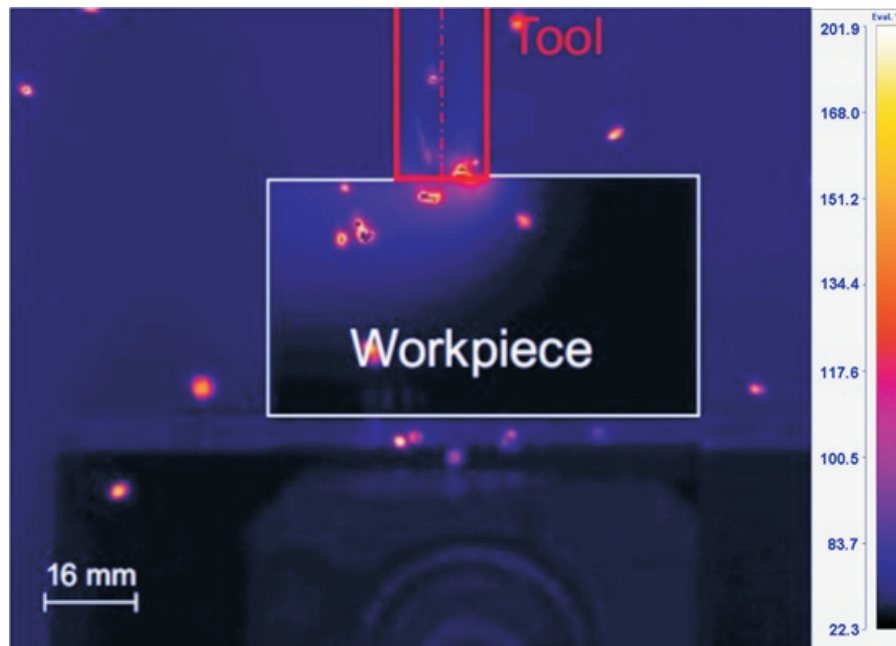
**Figure 4** Magnesium alloy (AZ91HP) during milling operation with  $v_c=105$  m/min

Next analysis tool labeled as vertical into IR Control workspace indicates location of outer diameter of the end-mill cutter. Intersection between two lines determine position of the cutting edge vertex. These two features are essential to determine numbers of frames in which the cutting process begins and finishes. Analysis line called (78mm) was used for rescaling IR image from pixels to millimeters.

In order to the fact that temperature range during cutting process turned out to be very wide, it was necessary to apply superframing method which dynamically extended measuring range of IR camera. Four presets were employed to ensure proper measuring range. Unfortunately application of this method caused decrease of effective frequency of recorded frames from 400 Hz to 100 Hz.

## 5. Results

In order to great number of obtained data during tests (about 4000 frames per test) it was essential to select repeatable period of time to evaluate temperature distribution into cutting zone. It was the time when end mill cutter reached half distance of the sample. This moment of time was arbitrarily chosen. Example of the frame is presented in Fig. 5.



**Figure 5** Magnesium alloy (AZ91HP) during milling operation with  $v_c=105$  m/min

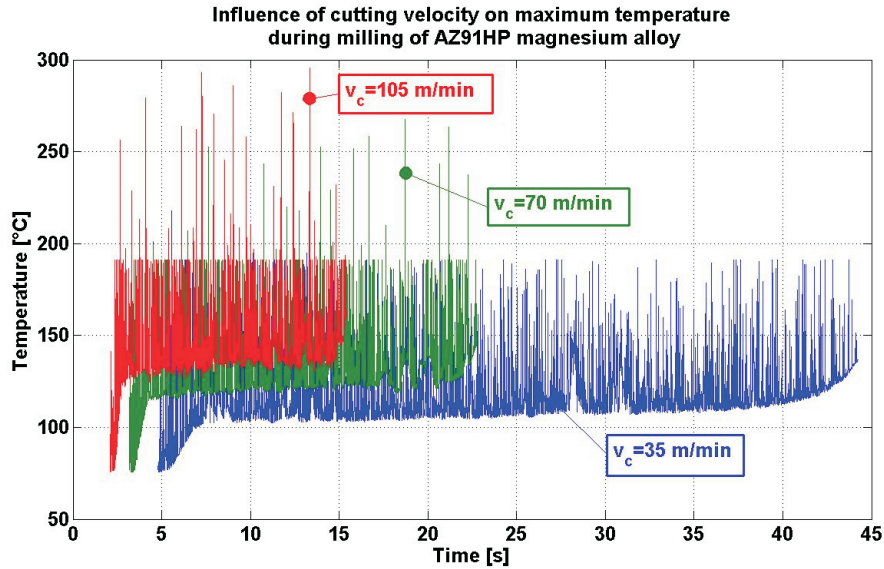
In the presented figures we can notice that during cutting magnesium alloy AZ91HP discontinuous chips were formed. Considering temperature levels, maximum temperature obtained from analyze tool called "horizontal" showed in Fig.4 was detected as 202 [°C].

On the base of experimental methodology described previously, only selected cutting parameters were investigated in the paper. To make comparison of influence of cutting velocity on maximum temperature, three IR sequences were recorded and taken into consideration. For evaluating repeatability each test was conducted three times. Parameters employed during experimental test are presented in Tab. 4.

**Table 3** Selected machining parameters

	Test no.	n [rev./min]	$v_c$ [mm/min]	$f_z$ [mm/tooth]	$v_f$ [mm/min]	$a_p$ [mm]	$a_e$ [mm]	$T_m$ [s]	$L_m$ [mm]
AZ91HP	1	696	35	0,055	115	1	5	41	78
	2	1393	70	0,055	230	1	5	21	78
	3	2089	105	0,055	345	1	5	14	78

On the base of recorded IR sequences, results were elaborated. Results concerning magnesium alloy is presented in Fig. 6.

**Figure 6** Influence of cutting velocity on temperature during cutting AZ91HP samples

On the base of presented results we can observe increase of temperature values with increase of cutting velocity. For better understanding intermittent cutting effect during milling process results presented in Fig. 6 were collected in boxplot graph showed in Fig.7.

Investigating boxplot presented in Fig. 7 increase of temperature into tool-workpiece interface has been observed. Maximum temperature detected during tests gained value 295 [°C] for cutting velocity  $v_c = 105$  [m/min]. Analyzing median values the same relationship between cutting velocity and temperature has been observed.

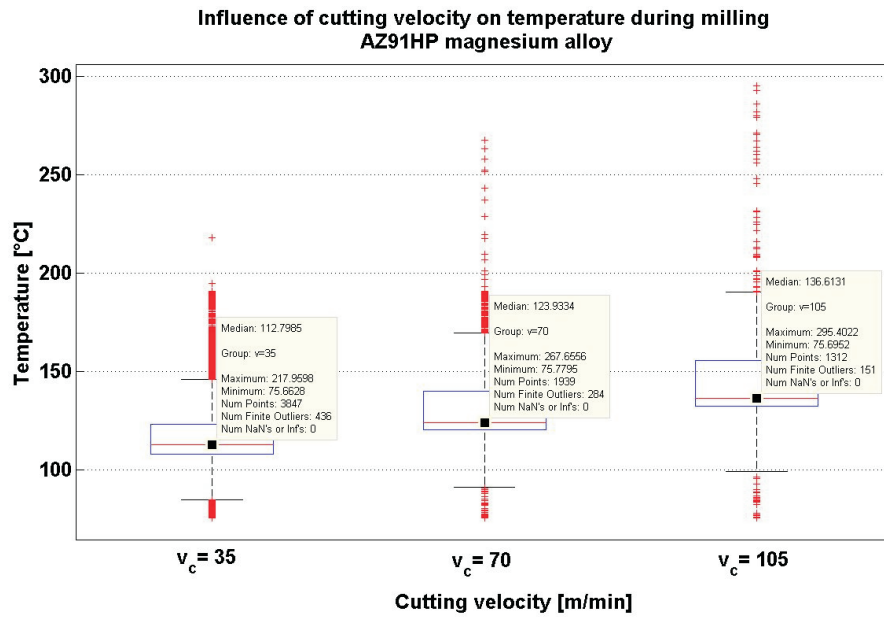


Figure 7 Comparison of different workpiece materials during milling process

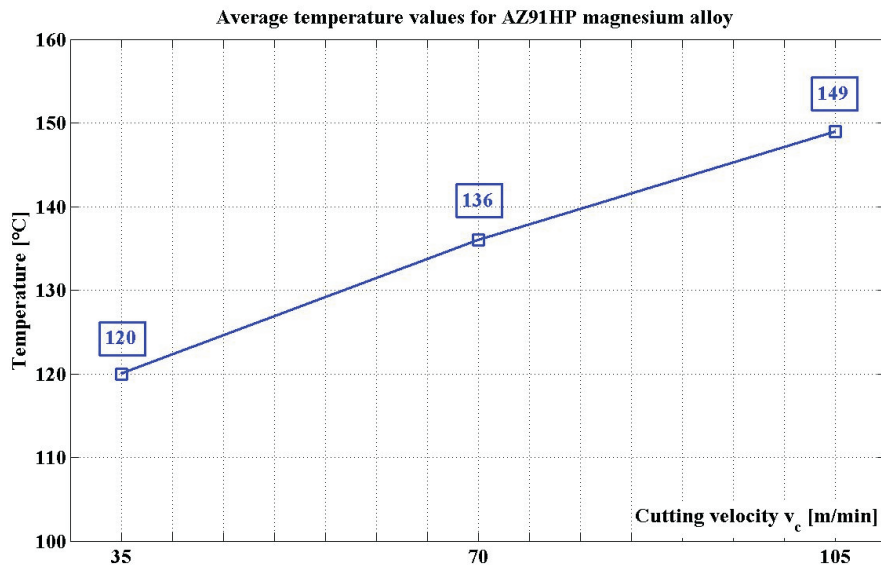


Figure 8 Average temperatures detected during milling AZ91HP magnesium alloy

To clearly illustrate influence of cutting velocity on temperature into cutting zone, average temperature values were calculated. The data without heating phase were only taken into consideration. In this case temperature values are lower than maximum temperatures observed during tests but their values are more repeatable. Results concerning this evaluation method is presented in Fig. 8.

## 6. Conclusions

By employing IR measurement technique it is possible to observe temperature distribution and even monitor temperature of chips created during manufacturing process.

On the base of results presented in Fig.6 and Fig. 7 it is possible to investigate interrupted cutting phenomena, however high frequency of recorded data should be applied.

Better results can be obtain when data without heating phase is taken into consideration. Due to limited dynamic range of IR camera it is possible to get improper signal for the highest values appeared into cutting zone. For this reason preliminary tests with different setting of IR camera should be done.

Future research should consider other areas into cutting zone such as tool temperature, chip temperature. Moreover force measurement during cutting test should be done for obtaining data for future research concerning simulations and working out mathematical model of end-milling process.

## References

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