

# Complex Process Monitoring of Cutting Hybrid Metal Structures

Ferenc Dömötör / Balázs Vehovszky / Zoltán Weltsch / Szilárd Németh / György Terpó

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## Abstract

The behavior of the cutting edge of the tool during the cutting process, especially the impact of the boundary surfaces of different materials has been studied by several authors. In this paper the latest results, achieved by our team, are reported. Several methods of the complex diagnostics of the cutting process of metal composite structures, including cutting force measurement, vibration analysis, high speed camera and thermography were successfully used for this purpose. It was found, that the boundary surface of the different materials has a big impact on the cutting force, the vibration and the temperature of the tool, which can be monitored very effectively with this complex technique.

## Keywords

process monitoring · hybrid materials · cutting force measurement · thermography · vibration diagnostics

## Acknowledgement

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## Ferenc Dömötör

Department of Automobiles and Vehicle Manufacturing, Budapest University of Technology and Economics, Stoczek u. 4., H-1111 Budapest, Hungary  
e-mail: domotor@kgtt.bme.hu

## Balázs Vehovszky

## Zoltán Weltsch

Department of Automobiles and Vehicle Manufacturing, Budapest University of Technology and Economics, Stoczek u. 4., H-1111 Budapest, Hungary

## Szilárd Németh

Gamax Laboratory Solutions Kft., Bartók Béla út 15/d., H-1114 Budapest, Hungary

## György Terpó

SKF Svéd Golyóscsapágy Rt., Csata u. 25., 2040 Budaörs, Hungary

## 1 Introduction

The Department of Automobiles and Vehicle Manufacturing of BME some years ago as a partner of an EU sponsored project (2004–2006) took part in the research project of the investigation of economically and environmentally friendly cutting process. The results have been published in several reports by Ozsváth et al. [6, 7] and Dömötör et al. [1–5]. Encouraged by the success of the project it seemed to be advisable to develop the results towards the complex diagnostics of the technology. In this stage of the project the vibration measurement data together with the thermo camera and high speed camera pictures are presented. Also the cutting force has been measured and the data were processed by the MatLab software. It was found, that the boundary surface of the different materials has a big impact on the various parameters, which can be monitored very effectively with this technique.

## 2 The cutting process

The investigated process was an orthogonal cutting on a lathe, located in our laboratory. The test rig used for the measurements can be seen on Fig. 1.

The main parameters of the cutting were as follows:

- speed of the spindle:  $n = 265$  rpm,
- feed rate: 0.0125 mm/rotation,
- width of the rim (cut): 3 mm.

The tool itself was a Mircona-1 L151S-2525x20x5-EB holder, and an SHL 205 HT cutting insert.

## 3 Preparation of the samples to be tested

The purpose of our research was to monitor the main parameters of the transient process, when the tool passes the contact surface of the hard-soft and soft-hard components. For this a special “hot dog” type specimen was developed. The cylinder was made of aluminium alloy AlMgSi1F30, and the thorn was made of C45 steel. Diameter of the Al cylinder is  $\varnothing 110$  mm, while that of the C45 bar was  $\varnothing 22$  mm before turning (see Fig. 2).

In order to provide plugs with different hardness, heat treatment methods were applied. The 5 plugs were quenched at the

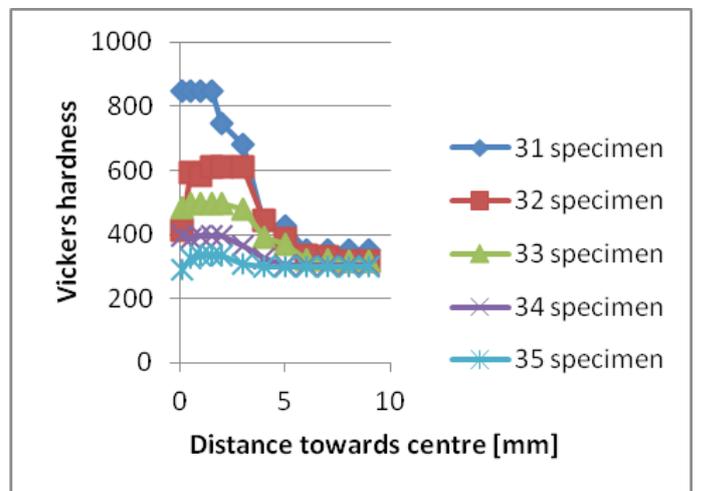
**Fig. 1.** Setup of the testing equipment and instruments



**Fig. 2.** Specimens of the experiment



**Fig. 3.** Micro hardness of the thorns of the different specimens (Nr3, Nr32, Nr33, Nr34, and Nr35)



same conditions, and afterwards tempered for 1 hour at  $T = 100, 200, 300, 400$  and  $500\text{ }^{\circ}\text{C}$  temperature, respectively. Plugs were fitted into the aluminium cylinders by heat shrinkage method.

Micro hardness of the thorns was determined by the so called indentation method, using a Hanneman type equipment. The force applied was 1 N, while for the hardness measurements the Vickers method was used. As it is obvious from the Fig. 3. the hardness of the thorns are different in the range of radius 0,5 – 6 mm from the outer surface of the cylinder towards the centre.

#### 4 Cutting force measurement and data processing by the Matlab software

The cutting was measured by a KISTLER 9257A type 3 Component Dynamometer. Sampling of the analogue data was carried out by a speed of 10 kHz. After using an A/D converter the digital data were processed and monitored by the MatLab software.

Where the probe is theoretically homogenous (alloyed aluminium), there no special impact can be seen on the diagram, and so it is nearly flat.

However, where the tool hits the hole, there the cutting force becomes zero. On the other hand, when the tool hits the hard thorn, then in this case a strong shock pulse can be observed (Fig. 5) on the time signal.

#### 5 Vibration measurement

For the vibration measurements a CMVA60 vibration analyser and data collector, made by SKF has been used. The measured vibration parameter – among others – was the so called Enveloped Acceleration (ENV1). The CMSS 2200 type accelerometer was also made by SKF. It has 100 mV/g sensitivity. Input and spectrum setup parameters were as follows: frequency range: 1-400 Hz, resolution 3200 FFT lines, average number 1, Peak to Peak, Hanning window.

All these diagrams (Fig. 7, 8, 9) are a proof on the strong influence of the thorn hardness. The harder the thorn, the higher the amplitude of the impact.

#### 6 Measurements by the thermo camera

Thermal pictures have been taken by a FLIR A325 camera. Naturally, only relative temperature can be seen on the pictures, because the emission factors could not be determined exactly. Moreover, an exact emission factor does not exist, because of the different optical features of the hybrid material. Consequently, the temperature values are only relative values.

As a result of the measurement it can be seen, that the temperature of the chips is changing between  $50\text{ }^{\circ}\text{C}$  and  $350\text{ }^{\circ}\text{C}$ . Also it can be observed, that there is a certain periodicity of the temperature variation, although the sampling frequency (Shannon rule) is certainly not enough to get a proper picture.

On the other hand, the temperature of the tool also depends on the hardness of the plugs. As shown on the Fig. 11 the extremely hard plug (Nr31, tempered at  $100\text{ }^{\circ}\text{C}$  only) has a strong influence

on the tool temperature, which is changing periodically. The softest plug on the other hand has practically no influence on the tool temperature, which remains nearly constant in time in this case (Nr35 specimen).

#### 7 Pictures, taken by the high speed camera

A high speed camera of type OLYMPUS i-speed 2 has been used take photos of the process. The main parameters of the high speed camera: colour recording (max. speed: 150000 F/s), max. res.: 1280\*1024 pixel. The maximum time interval can be increased up to 180 sec if the resolution is decreased accordingly. For the camera a high powered light source, independent from the frequency, has been used: Olympus, ILP-1.

The formation of the chip can be seen on the Fig. 7. It can be observed, that the chips of different material immediately separate from the specimen, and consequently no continuous chips can be formed during the cutting.

#### 8 Checking the geometry of the specimens

After the measurement the geometrical shape of the specimens has been checked. At first the roundness has been checked, and a considerable deviation from the circular shape has been found in all 5 cases (Fig. 14).

Surface parameters have been checked by a MarSurf XCR20 equipment and software. It was found, that the deviation from roundness can be as high as 0.41 mm. On the other hand, the highest values of the surface roughness parameters (Nr34 specimen) were as follows:

$$R_a = 2.227\mu\text{m}$$

$$R_z = 7.912\mu\text{m}$$

$$R_{\text{max}} = 8.32\mu\text{m}$$

#### 9 Metallographic structure of the plugs

In order to “double check” the mechanical properties of the specimens, a metallographic test has been carried out. Results of the tests can be seen Fig. 18 (martensitic structure, very high hardness) and Fig. 19 (bainite + perlite, definitely lower hardness).

The surface roughness of the Nr34 specimen is extremely spectacular, as it corresponds to a vibration of 3427 Hz at rotational speed of 265 rpm of the spindle.

#### 10 Conclusions

Micro hardness of the plugs of the various specimens (having different heat treatment) is changing along the radius of the plug. The hard thorn is providing a very strong impact (excitation) on the cutting force and consequently on the vibration of the tool as well.

The impact of force can be quite well approximated by the shape of a square function in the time domain and consequently it has the similar pattern (FFT of a square function) in the frequency domain as well.

Fig. 4. Setup of the KISTLER dynamometer

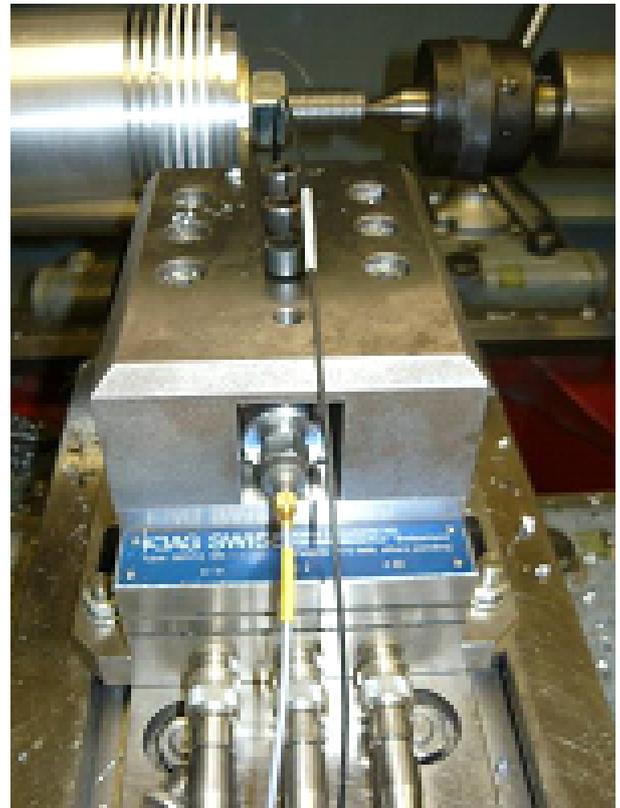


Fig. 5. Time signal of the force measurement

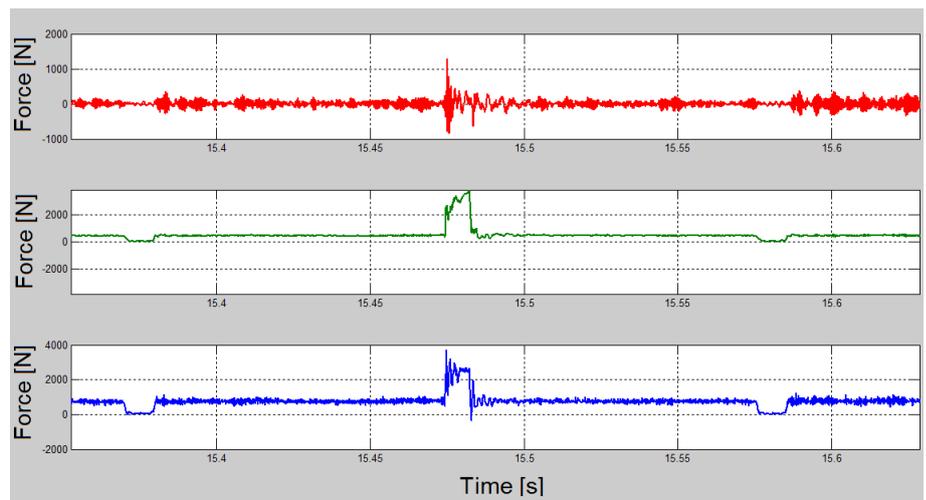
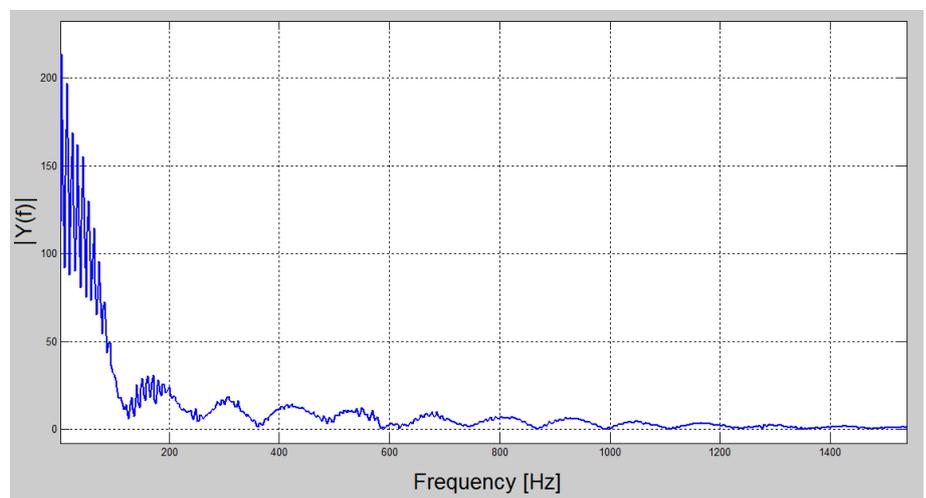
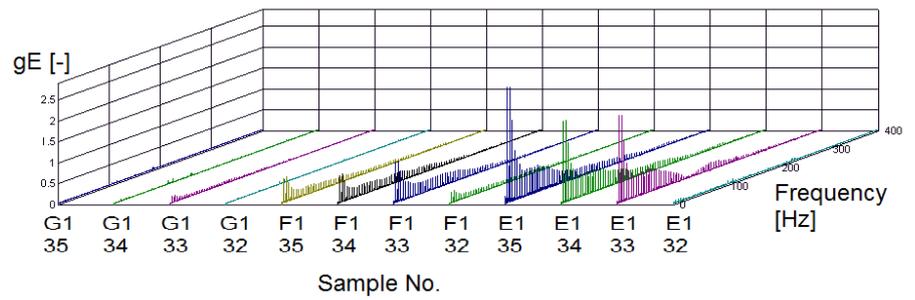


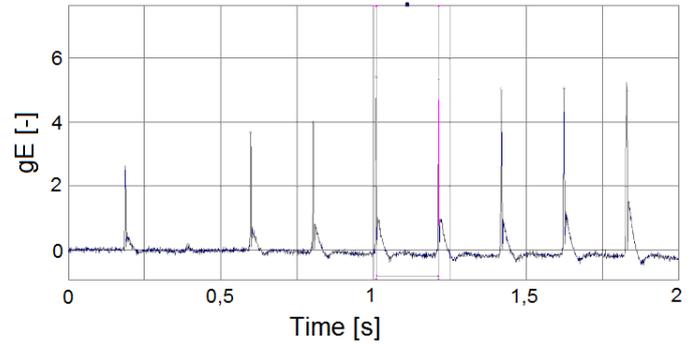
Fig. 6. Spectrum of the force measurement (Impact section of the time signal on Fig. 5 after FFT)



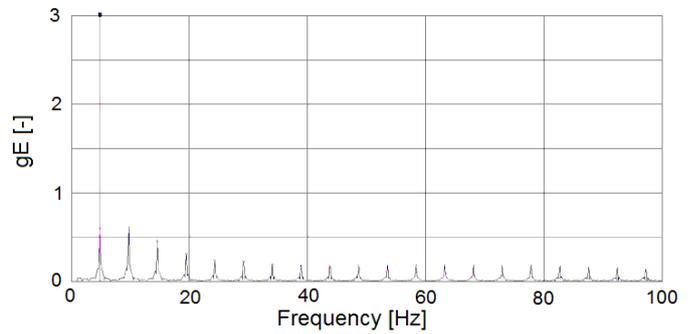
**Fig. 7.** Palogram of the vibration spectra (Spectra of different specimens – vertical direction)



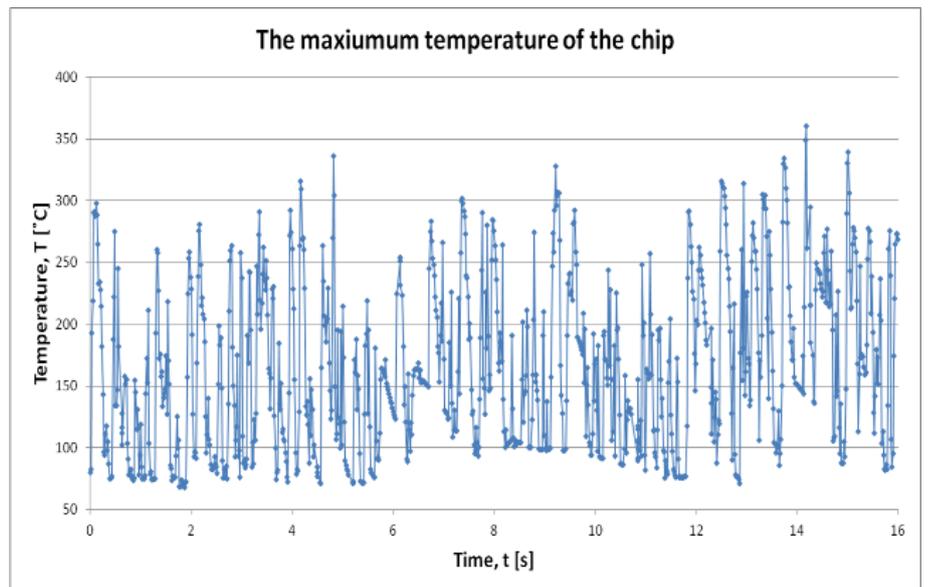
**Fig. 8.** Time diagram of the vibration (Vibration velocity, vertical direction 35F1 specimen)



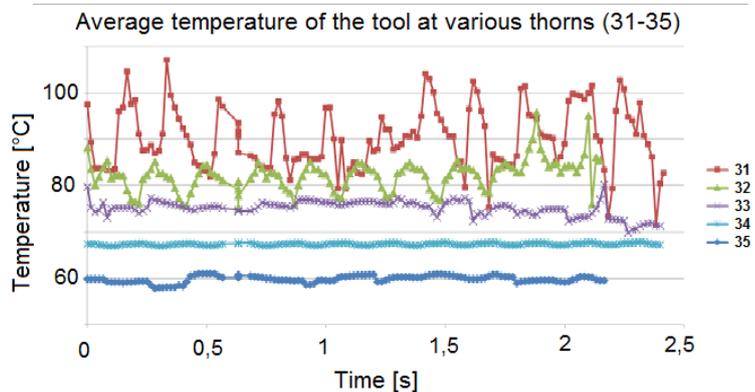
**Fig. 9.** Vibration spectrum (Vibration velocity, vertical direction 35F1 specimen)



**Fig. 10.** Thermal picture of the chips (Temperature vs. time)



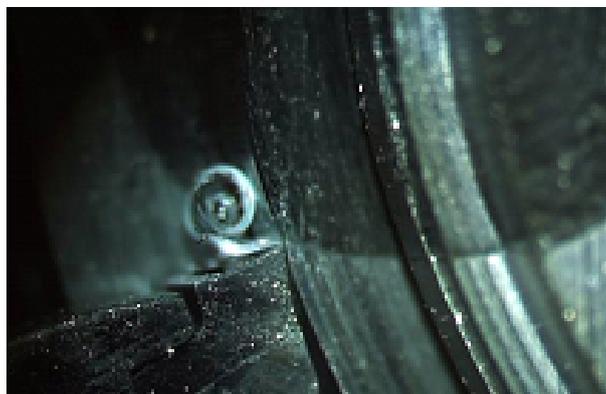
**Fig. 11.** Temperature of the tool tip when cutting different specimens (Nr31, Nr32, Nr33, Nr34 and Nr35 respectively)



**Fig. 12.** Formation of the chip (Picture taken by the high speed camera)



**Fig. 13.** Formation of the chip when the tool hits the boundary (Picture taken by the high speed camera)



**Fig. 14.** Deviation of the circular shape of the specimen

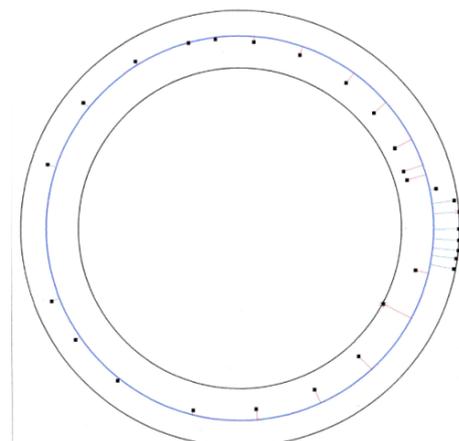


Fig. 15. Surface roughness of the specimen Nr34

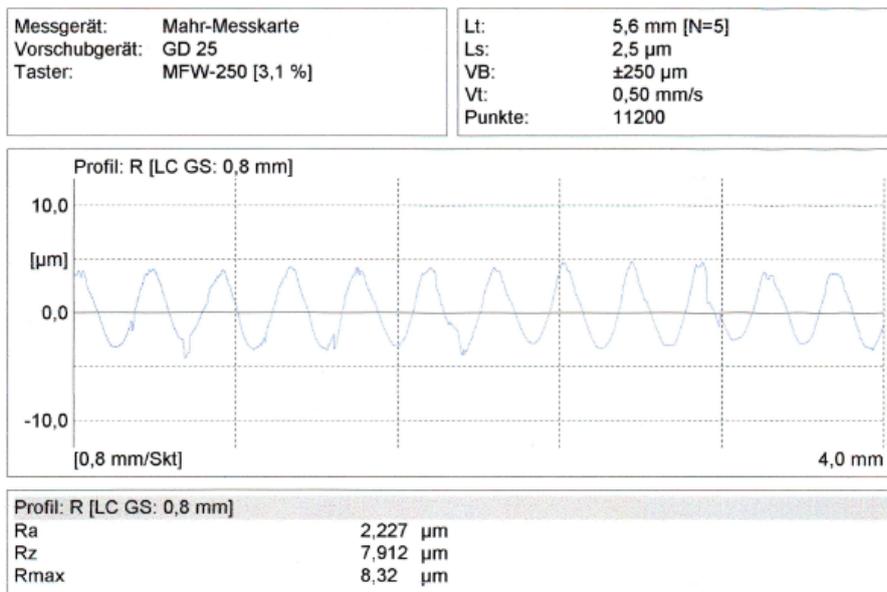


Fig. 16. Surface roughness of the specimen Nr34

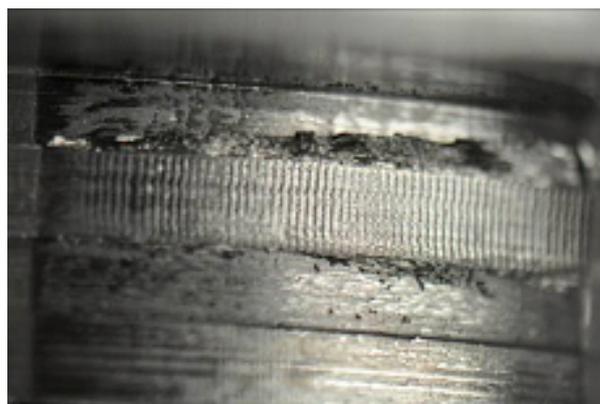


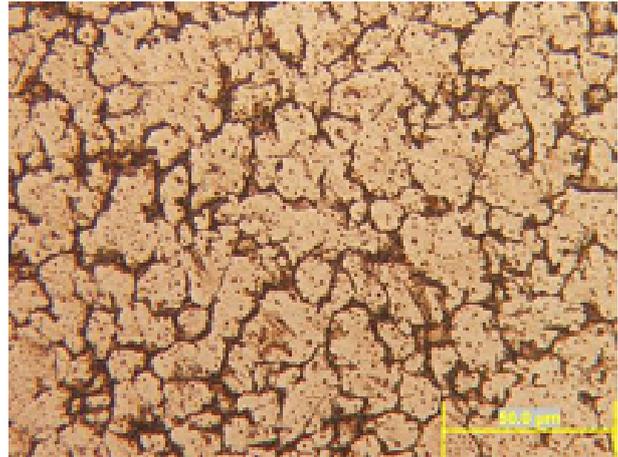
Fig. 17. Specimens, prepared for metallographic testing



**Fig. 18.** Metallographic texture of the specimen  
(Nr1B specimen 500:1 scale)



**Fig. 19.** Metallographic texture of the specimen  
(Nr5B specimen 500:1 scale)



The temperature of the tool is changing with the Vickers hardness of the plug. Moreover, the harder the plug is (Nr31 specimen), the higher the amplitude of the temperature function will be. The tempered thorn causes no fluctuation (Nr35 specimen) at all, while the quenched thorn (Nr31 specimen) causes a sinusoid like function, where the period of the fluctuation coincides with the period of the time of the rotation of the spindle.

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