Journal of Machine Engineering, Vol. 13, No. 4, 2013

carbon composites, machining,
scrap recycling

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PREPARATION AND RECYCLING OF CARBON CONTAINING COMPOSITES

Composites based on anthracite grains and carbon scrap containing also two mirror components were investigated. A milling machine allowing cutting speeds in the 100-400mm/min range connected to a piezoelectric dynamometer and a video camera was used. The debris formed was screened through sieves and chips with sizes larger than 1 mm can be recycled. Cutting resistance of the composite depends on the local distribution of the carbon scrap phase.

1. INTRODUCTION

There is a large variety of composites – including those which contain carbon in various forms such as carbons scrap, carbon black nanotubes, or graphite [1],[2],[3],[4]. Carbon containing composites have useful properties, including low thermal conductivity and good chemical resistance. These materials are used among others for lining blast furnaces, in electrolytic tanks, electric pig-iron furnaces and containers exposed to corrosive environments. Semi-finished product of linings are formed in blocks of different sizes and shapes, which are produced by compression. Manufacturing finished products typically requires machining – the main subject of the present publication. Literature on machining brittle materials deals extensively with rocks and ceramics while it has a long tradition [5], [6],[7]. We recall that according to the quantitative definition of brittleness B is inversely proportional to the elongation at break ε_b in tensile testing [8]. High B corresponds to low impact strength and vice versa [9].

In spite of very large number of publications in this area, an issue which seems to have received insufficient attention is analysis of machining of composites in terms of energy effects. This while separation of a material layer to be cut off requires a temporary force elevation above the local strength of material; in other words, energy is needed to remove the chip from the workpiece. This energy is converted into effective work of cutting. We

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note that the velocity of crack propagation is considerably higher than the cutting speed, in fact by two orders of magnitude. Hence the energy level drops immediately after the crack starts propagating through the workpiece material. The energy effect is dominant and the actual mechanism of permanent deformation does not change in a very wide range of the cutting speeds. This allows us to perform reliable cutting tests at low speeds (hundreds of mm/min).

There are some important advantages associated with low velocity tests: dynamic influence of the work station on the cutting process is practically eliminated; also the equipments costs are low. The work station behaves as a compression spring which accumulates potential energy of the whole system. Variability of cutting force when brittle material is machined represents a stochastic process and probabilistic methods of description can be applied. Energy type interpretation of the process has to involve necessarily both deformation and force.

For better understanding and description of the energy aspect of the treatment process we have used a work station equipped as described below.

2. WORK STATION AND METHODOLOGY OF EXPERIMENTS

Figures 1 and 2 show the work station used. The construction is based on the stiff vertical milling machine FSS 400-V, WMW Heckert Germany. A milling head with the tool is blocked by a special yoke; the samples are mounted on a standard vise. Cutting tool is of the single point type and mounted onto on immobilized face milling head. One brick of the workpiece material is attached to the gripping jaws of the dynamometer. The table of milling machine allows slow cutting movement in the 100 - 400 mm/min range. A 3-axis Kistler type 9265B piezoelectric dynamometer is placed between the vise and the mill table and connected to a C1 111 charge-transfer amplifier. Data are recorded on a hard drive by a computer program which uses a data acquisition card from Ambex.

To follow formation of chips with a good accuracy, we use a high speed X-Stream XS-3 digital video camera. Cutting tool movement is measured with a Politach 505 vibrometer. We have investigated both free machining and non-free machining cases, applying a variety of back rake angles. A constant cutting area of 80 mm^2 was maintained. The main linear feed is executed by the workpiece, feed rate and cut depth are adjusted manually. The data so acquired are digitally post-processed with Diadem software from National Instruments. The data files are analyzed by a software that produces histograms of energy. Fig. 1 shows the stand with the work station schematically while Fig. 2 provides a photograph of the stand.

Needless to say, we need to perform the tests to detect all kinds of perturbations not caused by the machining process so as to identify and eliminate them. We take here the advantage of the fact noted above: the energetic effects dominate the process, hence the energy situation does not change over a very wide range of the cutting speeds. Perturbations that could influence the results manifest themselves at high velocities. At very low cutting velocities that we apply, such perturbations are minimal.

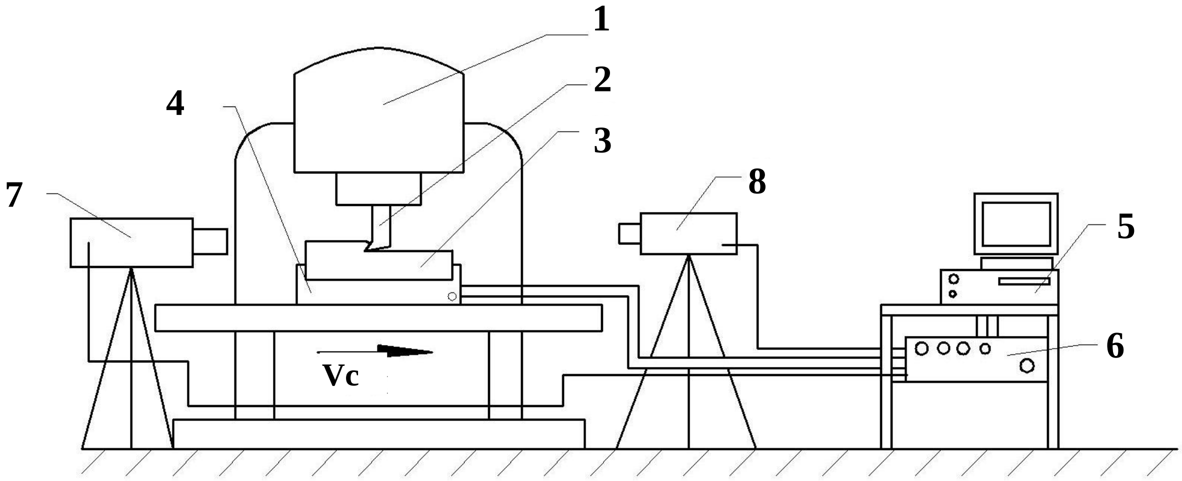

Fig. 1. Laboratory stand: 1) vertical FSS 400-V milling machine; 2) tool; 3) workpiece; 4) Kistler piezoelectric dynamometer; 5) data acquisition computer; 6) C1 111 charge-transfer amplifier; 7) high speed X-Stream XS-3 digital video camera; 8) Politach 505 vibrometer

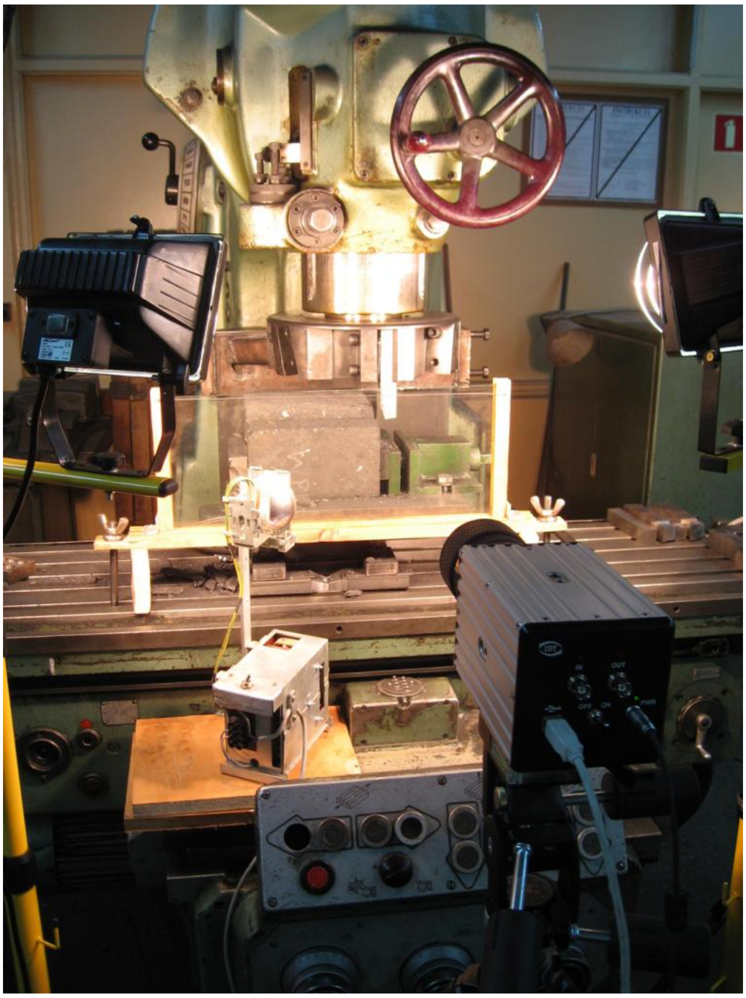

Fig. 2. Laboratory stand

3. MATERIALS STUDIED

WPW-65 carbon composite blocks are produced by SGL Carbon Group, Racibórz, Poland. The shape of the blocks is shown in Fig. 3.

Fig. 3. A WPW-65 carbon composite block

The blocks consist of 48.5 wt.% anthracite grains, 38.5% carbon scrap, 4.3 % dust, 8.7% clay bonding. Thus, two form of carbon constitute in total 87.0 wt. % of the total composite [10].

4. PROPERTIES OF COMPOSITES

We have determined several physical and mechanical properties of our composites: apparent density = 1.90 g/cm^3; porosity = 18.0%; compressive strength R_c from 18 to 45MPa; tensile strength R_m from 4 to 10MPa; flexural strength R_g from 6 to 12MPa. The ranges come from the fact that distributions of the constituents in the composites vary form block to block [11].

5. MACHINING RESULTS

Final shapes are obtained by machining, mainly milling. During the machining, discontinuous chips are formed. Fracture occurs in the primary deformation zone when the chip is only partly formed (Fig. 4).

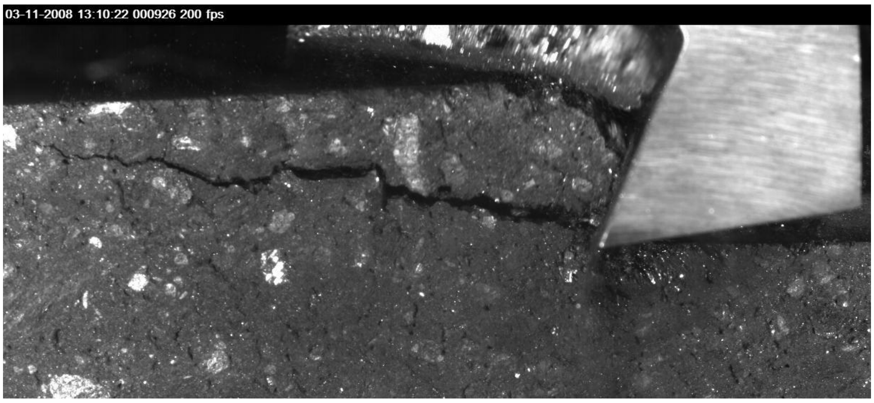

Fig. 4. Chip creation process

Machining is performed at high feeds and back engagements (cross-sectional area of the uncut chip exceeds *120*mm^2), when cutting velocities are approximately 0.4 m/min. For obvious environmental and economic reasons, we need to consider reusability of the chips. After machining, some of the chips produced can be re-used in the carbon composite blocks production process. However, their reusability depends on the scrap size. Only chips with sizes larger than *1*mm can be used. From the industrial point of view, the granulometric composition of scraps is essential as a process indicator, apart from the tool life and the quality of machined surfaces. Optimization of machining process for carbon composites such as our WPW-65 requires certain conditions to be fulfilled: roughness Ra < Ra-st , tool life $t_0 > t_{st}$ (Ra-st, and t_{st} are respectively the roughness and tool life limits). The values of Ra-st and t_{st} have been imposed by the recipients of the coal blocks.

The profile roughness parameters Ra is the arithmetic mean deviation of the assessed profile:

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|Z_i| \tag{1}$$

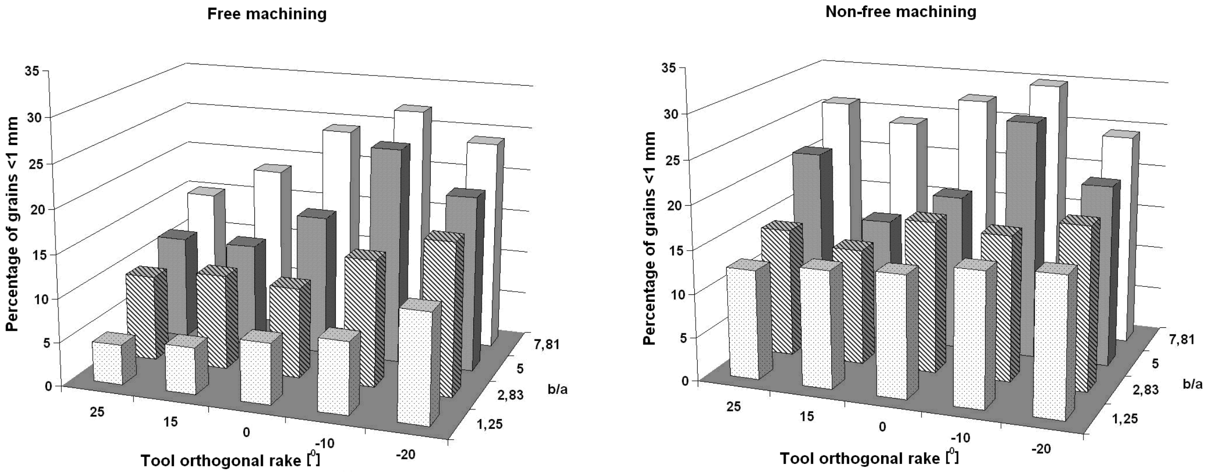

Fig. 5. Granularity graph for free and non-free machining for tool orthogonal rake for cross-section cutting layer b/a

Here n is the number of locations at which the value of the vertical coordinate Z_i determined on a given X-Y surface perpendicular to the Z axis.

After machining, debris of particles from the process are being screened through a column of sieves. The results are two fractions, one with debris large than *1* mm and the second containing particles smaller than *1*mm. Some results of machining are displayed in Fig. 5. We see how variety of cutting conditions can influence the final effects of machining.

Determination of the self frequency of the station (tool machine – workpiece – holder – dynamometer system) is one of the most important steps of systematic investigations. Then noise effects such as the machine resonance, power supply noise, and equipment noise are subtracted from the output signal. Tests of work station displacements without machining and impact tests with free vibrations remaining provide information about the noise components. Figure 6 shows original as well as trimmed signals for the caser of both free and non-free machining.

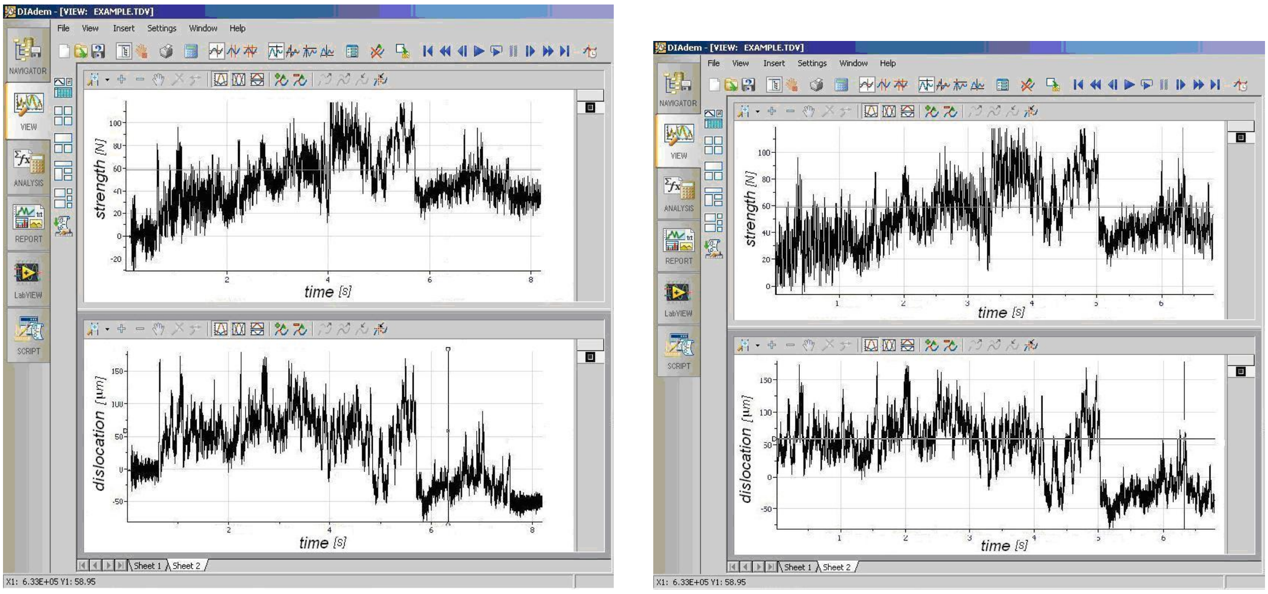

Fig. 6. Original and trimmed signal: left free and right non-free machining

The input stage signal is used for the maximum force analysis. Tests are repeated five times, and mean values of the maximum cutting force and the respective standard deviations are derived. Figure 7 provides examples of signal analysis.

Knowledge of movement and strength allows the determination of potential energy on the tool. This energy is converted into useful cutting work. We note discontinuous nature of the process of energy transformation. Our conglomerate carbonaceous material has pores, inclusions and impurities. Their random distribution in the mass of the material results in local variation of the cutting resistance. We obtain a distribution of the random sample energy pulses transmitted by the tool into the material. An example of such an energy distribution is displayed in Fig. 8. The theoretical line 4 has been obtained by setting the level of energy required to detach a grain size of *1*mm.

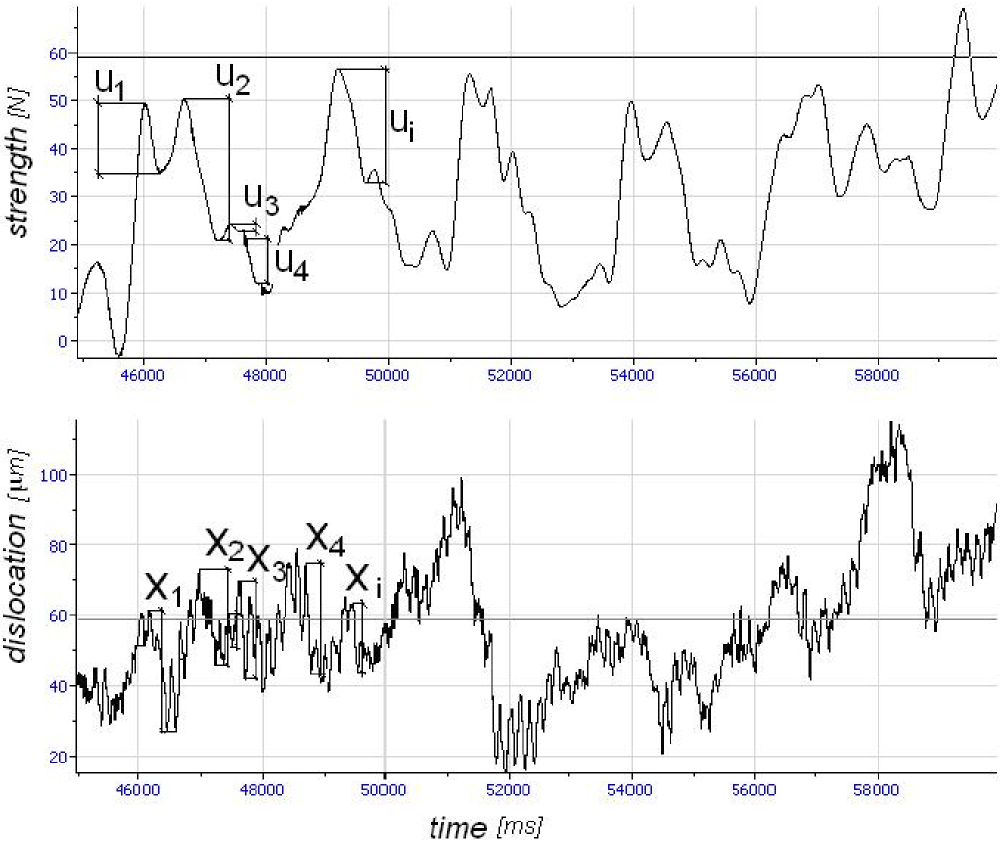

Fig. 7. Energy computation method

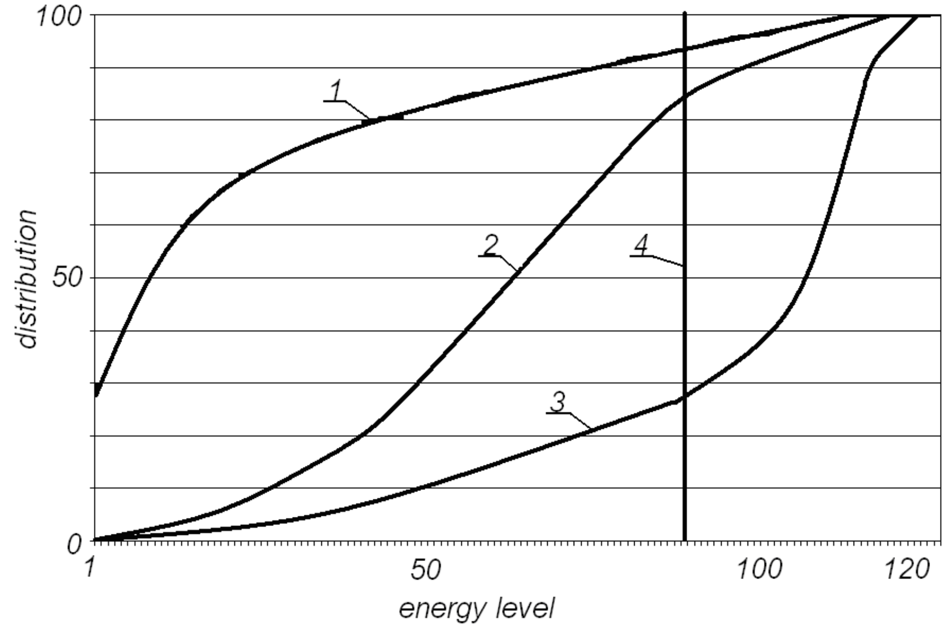

Fig. 8. Cumulative distribution function graph: 1, 2, 3 are actual processes, 4 is the theoretical process

We see in Fig. 8 that the experimental curves: one designated for the carriage of positive geometry, 2 determined for the tools of geometry neutral and 3 determined for the tools of geometry negative deviate significantly from the theoretical curve 4, which was determined on the basis of the calculation of the level of energy needed to create the characteristic particle dimension 1mm. This fact has evident an sequences for the capability to recycle the chips for need in the machining process.

6. A SURVEY OF RESULTS

In our carbon composites the machining results depend significantly on the method of machining (free or non-free), on the back rack angle γ_0 and on the cutting area.

Although our methodology of investigations introduced in this article pertains to carbon composites, the same method can be used to analyze machining of other brittle materials.

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