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BORING BARS OPTIMIZED WITH POLYMER CONCRETE

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Abstract: *This paper shows the dynamic properties of steel boring bars modified with the composite material polymer concrete in order to reach good vibration damping during chipping. Polymer concrete has very positive damping properties; therefore the filling out of empty spaces in machine bases as well as the filling out of hollow cavities in civil engineering is a well known application of polymer concrete. On the basis of this knowledge, boring bars with polymer concrete as a supplemental material were manufactured and investigated using theoretical and experimental methods. The modifications of the steel boring bars consist of polymer concrete cores with different diameters in the center of the boring bar. The methods employed in this investigation include the finite element method for static behavior, the experimental modal analysis for dynamic compliance and conclude with chipping experiments.*

Key words: *tools, boring bar, polymer concrete, vibration damping.*

1. INTRODUCTION

Vibrations are caused through undesired relative movements between tool and work piece. The stimulation of the vibrations can be released through inner machine forces respectively impulse form forces of chip formation process. The occurring vibrations are responsible for the limitation of the work piece surface quality and for the recoverable productivity. In the interaction between machine tool, tool, device and work piece, the dynamic and static stiffness are the deciding criteria.

Polymer concrete has had great importance as a supplemental material as well as a substitution material in civil engineering and machine building for years. Polymer concrete shows a 6 to 8 time higher damping capability in comparison with steel, therefore the filling out of free space in steel constructions is a best-known method to improve the dynamic behavior of structural elements [2].

Tools like boring bars with long overhangs are a very important production means in the metal-working industry and they are indispensable for boring. Several methods of resolution to improve the dynamic stiffness of boring bars in practice exist. The methods vary from electronic to mechanical solutions.

The solution method described in this paper shows a simple and quite effective modification of boring bars with the goal to improve the dynamic behavior of overhanging tools and to keep the static stiffness on a nearly comparable level. In addition to technologic properties the economic factors are of interest and are also described in this paper.

2. BORING BAR MODIFICATION WITH POLYMER CONCRETE

The application of polymer concrete is limited to the core in the centre of the boring bars. The reason for this is that the necessary mechanical strength of the boring bar cannot be reached by using polymer concrete as a substitution material. The static stiffness of the tool body manufactured of polymer concrete would not be able to withstand the occurring stress during chipping. Additional reasons include the unfavorable ratio between tensile and compression strength (1:10) and the sensitivity to blows (brittleness).

The modified boring bars show an overhang of $5 \times D$ (D = diameter of boring bar). This overhang was selected because boring bars of steel are normally suited to a maximum overhang of $4 \times D$.

Two different diameters of polymer concrete cores were selected because investigations in the filed of jig-making have shown that, with an increasing quantity of polymer concrete the damping behavior may be improved. But with an increasing volume share of the polymer concrete the static stiffness will be also reduced through the lower modulus of elasticity of polymer concrete [3].

The length of the polymer concrete core is 85% of the total length of the boring bar. A further elongation of the polymer concrete core is not possible due to the diminution of the tool diameter on the cutting head.

2.1. Composition of polymer concrete

Polymer concrete with epoxy resin as a binder and quartz sand as a filler material shows the best result with respect to mechanical strength and material shrinkage of all the types of polymer concrete. A very low shrinkage of the polymer concrete is very important in order to reach a well and holohedral connection between the inner side of the tool shank and the outer side of the polymer concrete core.

The maximum grain diameter of the filler material is limited to 3.6mm in order to maintain positive rheological properties during pouring, and to keep the processing specifications of polymer concrete bodies. The polymer concrete consists of a ratio of 12 % weight epoxy resin and 88% weight filler material. The quartz sand mixture should be composed according to Fuller's grading curve.

Fig. 1. Boring bars specimen.

2.1. Modification of boring bars

The first step for the modification of the steel boring bar is drilling the blind hole. Afterwards the polymer concrete can be poured in and compacted. The pouring and compaction of the polymer concrete must be done with a clamping device in order to achieve a sufficient degree of compaction and to ensure a good connection to the vibrator as well as to the vibrating table. The concluding production step is face grinding the polymer concrete core. Figure 1 shows the rear side of the modified steel boring bars and the reference steel boring bar for the experimental investigations. The dimensions and weights of the boring bars are also listed in Fig 1.

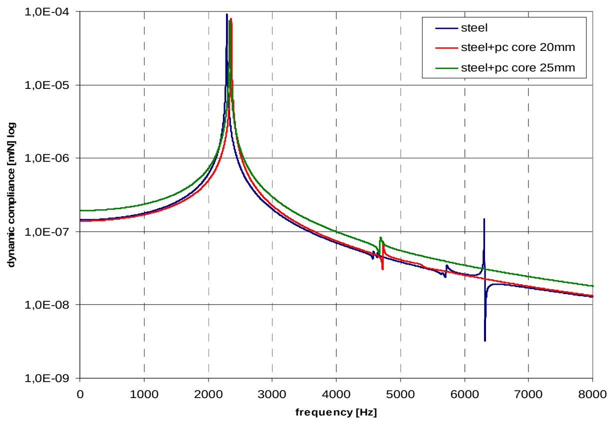

Fig. 2. Dynamic compliance frequency response.

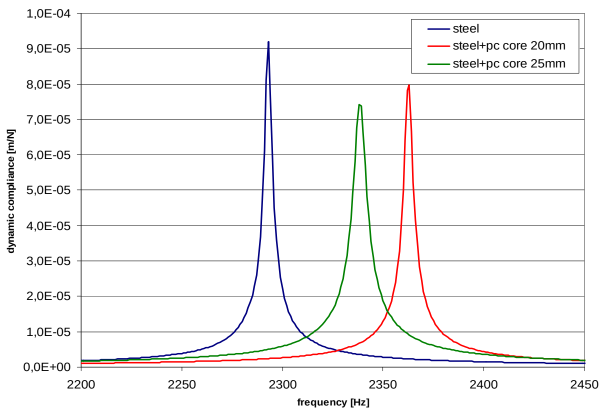

Fig. 3. Dynamic compliance of 1st natural mode.

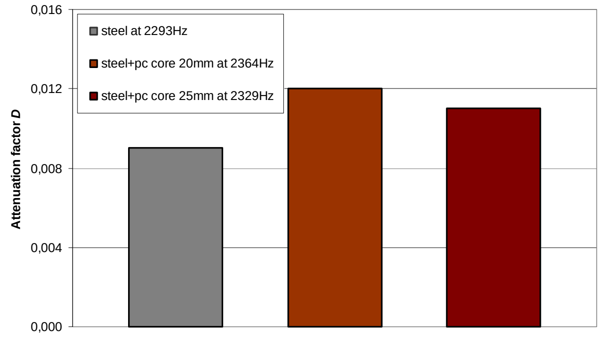

Fig. 4. Attenuation factors of 1st natural mode.

3. INVESTIGATION OF DYNAMIC AND STATIC BEHAVIOR

The dynamic as well as the static behavior have strong influence on the surface quality of manufactured goods. The standard approach for the investigation of dynamic behavior is the experimental modal analysis and consecutively the measurement of the surface roughness by the work piece machined [5].

3.1. Experimental modal analysis

The experimental modal analysis is the standard investigation method for the experimental characterization of a vibratory system with its natural oscillation parameters. The constraints of the experimental investigation consisted of the following conditions [4]:

- test specimen decoupled hang up;
- stimulation with impulse hammer.

The dynamic compliance frequency responses of the three boring bar test specimens are shown in Fig. 2. The first natural mode is especially important for the dynamic behavior of the boring bars during machining. The second and third natural modes of the boring bars show an essentially lower dynamic compliance (notice the logarithmic presentation of the dynamic compliance in Fig. 2). It may be assumed, then, that the influence is very low and therefore negligible during chipping.

The boring bars modified with the polymer concrete core show lower amplitudes of dynamic compliance in comparison to the steel boring bar in the first natural mode (Fig. 3). The positions of the natural frequency are also shifted to a higher position. Both criteria are indicators for improved dynamic behavior besides the attenuation factor *D* in the case of resonance. Figure 4 shows the experimentally determined attenuation factors with respect to first natural mode of the test specimens.

3.2. Chipping experiments

The lathe used for the chipping experiments was equipped with a numeric control to ensure constant chipping conditions.

The boring bars were clamped in a standard VDI tool holder (Fig. 5). The overhanging length of the boring bar was 200 mm (5× *D*) by 100mm clamping length during the experiment.

The work piece material used was 42CrMo4 because the material is medium-heavy to chip. The cylindrical work piece was prepared with a drill for boring.

The chipping experiment was done with two different setting parameters (cutting speed, feed rate) to obtain

Fig. 5. Boring bar during chipping.

Table 1

Setting parameters by chipping

Setting	Cutting speed	feed rate
1	40 m/min	0.2 mm/per rotation
2	40 m/min	0.1 mm/per rotation
3	20 m/min	0.2 mm/per rotation
4	20 m/min	0.1 mm/per rotation

information on the surface quality (average roughness height R_a) of a large field. The setting parameters are listed in Table 1. The cutting depth was kept constant at 0.5mm.

The setting parameters of setting 1 show the maximum cutting speed and feed rate which were possible with the steel boring bar. Higher cutting speed as well as an increased feed rate led to chattering during the chipping [1].

The results of the chipping experiments are shown in Fig. 6. The average roughness height of the machined surfaces shows essentially lower values on all four setting parameters by the boring bars with the polymer concrete core. The average roughness height was reduced on average by 34% on setting 1.31 % on setting 2.49 % on setting 3 and 33% on setting 4 by the work piece machined with the boring bars utilizing the polymer concrete core.

3.3. Static behavior

Static behavior was investigated with the finite element method.

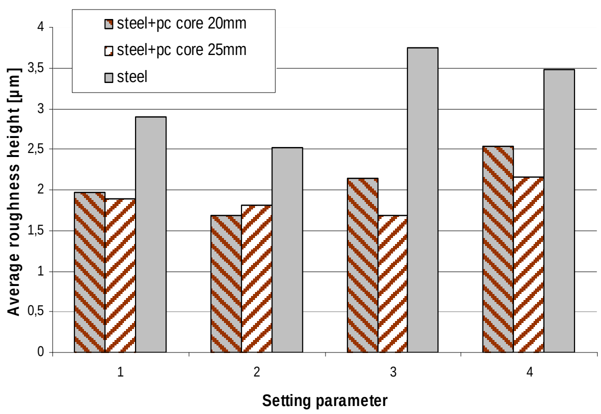

Fig. 6. Surface roughness (R_a) of work piece.

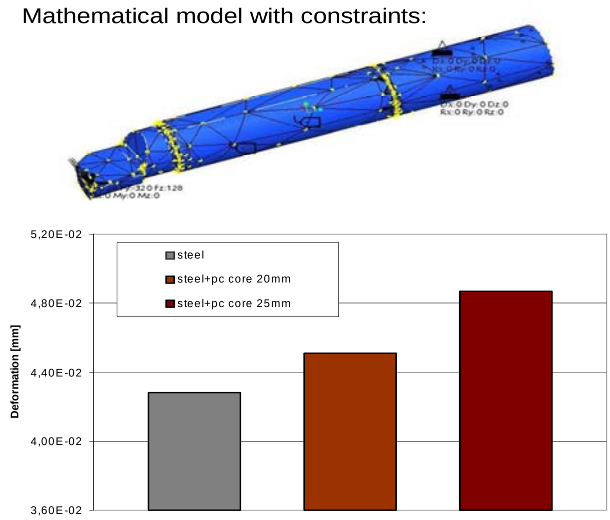

Fig. 7. Deformation of boring bars.

Table 2

Forces of setting 1 by chipping

cutting force	force of feed step	passive force
320 N	128 N	128 N

The forces assumed for the calculations are approximately equivalent to the occurring forces in practice at the setting parameter 1 (see Table 1). The forces used are listed in Table 2. The force of feed step and the passive force were each assumed to be 40 percent of the cutting force and used with their respective directions during chipping.

The mathematical model of the boring bar test specimen and the calculated results are shown in Fig. 7. The deformation values listed are the maximum displacement without respect to direction. The maximum displacement grows with the increasing diameter of the polymer concrete core. This is a consequence of the lower mechanical strength of the polymer concrete.

4. ECONOMIC EFFECTS AND ASPECTS OF OPTIMIZATION

The modified boring bars were investigated with respect to tool wear at the setting parameter 1 (see Table 1). The setting parameter 1 shows the largest material removal rate of all the parameter settings investigated. Furthermore, this setting represents the maximum possible material removal rate of the steel boring bar and was selected for this reason.

4.1. Wear of cutting edge

The test parameter used for the evaluation of tool wear was the flank-wear land width.
The results of the flank-wear land width with respect to time are shown in Fig. 8.

Tool endurance was reached within the 30 minutes because the flank-wear land width is set from 0.3 – 0.5mm when used in practice.

The cutting insert used on the boring bars modified with the polymer concrete cores show on average a 24 % longer endurance in comparison to the cutting inserts used on the steel boring bar.

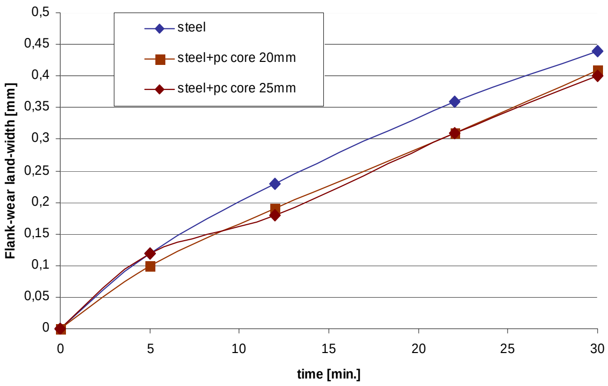

Fig. 8. Flank wear of cutting insert.

4.2. Additional costs of modification

The calculation of the additional costs through the modification effort is based on material costs and hourly wage rates of Germany in May 2008. Furthermore, the product calculation is based on a production batch of 100 pieces because technological equipment must be built (clamping device) for the production process and the costs may be significantly prorated. Figure 9 shows the calculation of the additional cost of the boring bars modification. The main share of the costs is originated through the drilling of the core hole because this step can not be optimized with respect to series production.

The modification leads to a rise of 15 % (average value) on the total price of the boring bar. If the increased price is considered with respect to improved cutting tool endurance, then the additional costs can be compensated in a short time during chipping. The necessary time for the compensation of the additional manufacturing costs is listed in Table 3. The time is based on the difference of the flank-wear land width at 0.3mm and on an average cutting insert price of 0.86 € a piece.

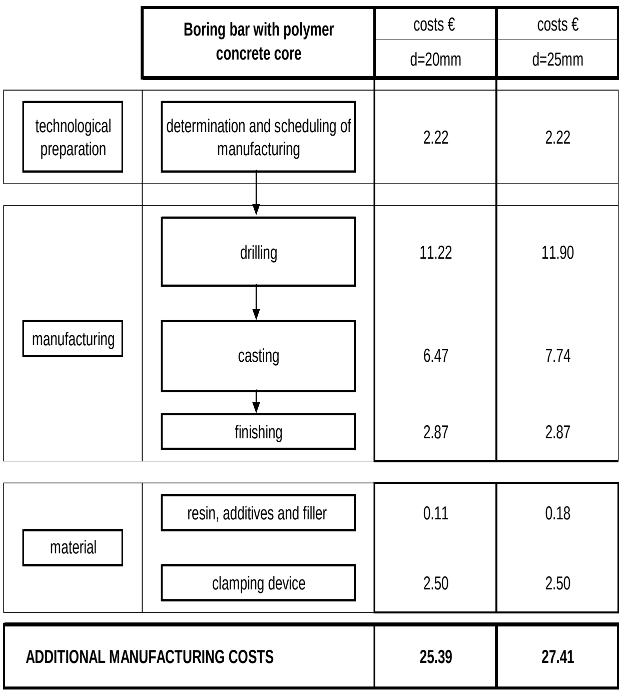

Fig. 9. Costs of boring bar modification.

Table 3

Necessary time for cost compensation

Boring bar	compensation time
pc core 20mm	123 h
pc core 25mm	133 h

5. CONCLUDING REMARKS

Boring bars only consisting of steel tend to vibrate (chattering) because of their long overhanging design. The consequences are a bad surface quality of the work piece and a higher cutting tool wear.

Boring bars optimized with polymer concrete show an essential improvement of the dynamic stiffness. The reduction of the static stiffness depends on the diameter of the polymer concrete core, but the calculated deformation is not out of an acceptable range. The optimization of the boring bars leads to a better surface quality of the work piece as well as to reduced manufacturing costs with respect to tool wear.

Extensions of end milling cutters and borer (with cutting inserts) show a construction design nearly comparable to the boring bars investigated. These types of tools also tend to vibrate because of their long overhanging design. The use of polymer concrete as a core can be considered a further meaningful application for tools.

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