New tooling strategies for ultra-precision machining

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Abstract

Today's optic industry shows a sure trend towards more precise optical surfaces, leaving regular geometries and introducing more and more complicated forms using materials not typical for up-machining. Within the process chains for generating such surfaces one of the great challenges is tool lifetime.

At Carl Zeiss the deterministic and economic production of high quality optical surfaces with complex geometries is pursued. To this end new tool geometries and tool material solutions are strived for, to overcome machining challenges for ultra precision manufacturing.

The definition and selection of proper diamond tools, their specifications and materials are complex issues.

One possibility to overcome the limitation of tool lifetime is to introduce a new sort of diamonds – the macle diamond.

1. Macle Diamonds

Macles are twinned crystals, meaning that two separate crystals intergrew now sharing some crystal lattice points [1]. The hardness of diamonds depends on the crystal orientation [2], Along a shared twin boundary macle diamonds are harder than conventional diamonds. The higher hardness is a result of self-stress at the crystal boundary of two merged mono crystalline diamonds. Some of the challenges of using macle diamonds are alignment of the correct crystal orientation, preparation of the cutting edge, performing pre-cutting and polishing, reducing waviness of the cutting edge and tool wear at the "merging-edge" and on the sides, etc.

2. Tool Wear

At Carl Zeiss possible processes for such macle diamonds have been discussed and were defined. A couple of test programs for proof of principal were designed. The goal of these tests was to determine if there are advantages in tool wear over conventional diamond tools. Statistical analysis gave some insights into relevant factors. For analysis six sigma methods were used.

2.1 Design of Experiment

In order to specify the influences of several parameters next to the choice of tools (standard or macle), a fractional factorial design of experiment was chosen. The factors were: tool, tool radius, depth of cut and chip cross section. All experiments were performed on nickel phosphor (eNiP 12%) plated aluminium samples. The point of tool wear was defined as change in micro roughness at a certain cutting distance [see figure 1 left]. To safe time, several cuts were performed on one sample, leaving rings which represent about equal cutting distance [see figure 1 right].

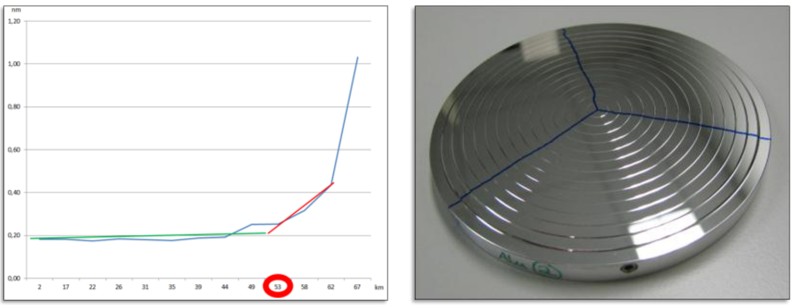

Figure 1: Left: Measurement of micro roughness in relation to cutting distance.
Right: Sample after cutting test, each ring representing equal cutting distance.

2.2 Evaluation of Results

Statistical evaluation of the results show that about 75 % of the influence on tool wear comes from the choice of the chip cross section or combined influences of chip cross section with other influences. The choice of diamond (standard or macle) has no significant influence on tool wear [see graph in figure 2].

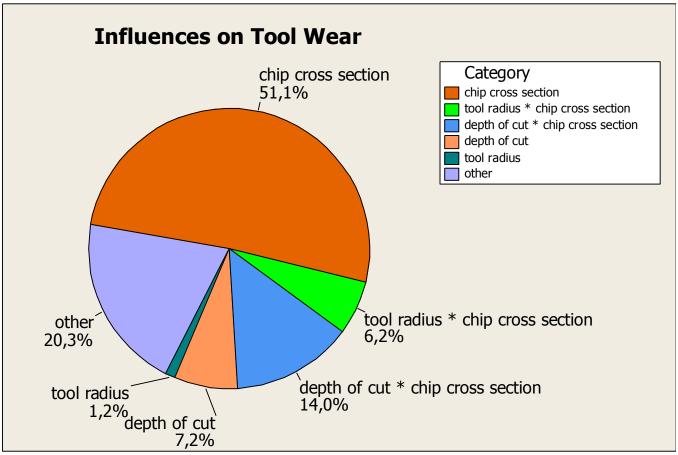

Figure 2: Statistical report on influences on tool wear.

As expected tool wear is reduced by reducing the chip cross section within the process. Also bigger tool radii lead to less tool wear. A little surprise was that tool wear is also reduced with greater depth of cut at the same chip cross section.

2.3 β-Risk

The statistical evaluation of factorial experiments always leaves a risk of misinterpretation, the so called β-risk. The presumed β-risk in this case was 20 %, the calculated effect was 40 %, meaning with 80 % surety the results of standard tools and macle tools vary less than 40 % from each other. Since 20.3 % of the influences on tool wear come from unknown sources [see figure 2], there is still a chance that the choice of tool has an influence on tool wear. There is just no valid proof found in the experiments with nickel phosphor samples. Since the variance of lifetime of diamond tools is relatively high, small possible differences cannot be proven without a lot higher time, effort and cost.

3. Work Piece Materials

Within the next year ultra-precision manufacturing with macle diamonds is supposed to be tested on diverse materials. It will be interesting to see, if these tools have a longer lifetime when used in materials, that are usually not suitable for diamond machining, like alloys with hard grains (Cr, Si etc. in Al or Cu), ferrous alloys, etc.

3.1 First Results

The hardness of workpieces is often one of the key functionalities. However, hard materials are not usually diamond machinable, some because of chemical reactions with the diamond at the cutting edge, others because of hard grains within the alloy which destroy the cutting edge physically. Several hardened metal alloys were tested. Some first results look very promising. While standard diamond tools degrade immediately, producing a rms surface micro roughness of around 70 nm, macle tools endure a long while producing a rms surface micro roughness of about 5 – 7 nm [see figure 3].

Figure 3: Hardened metal alloy machined with standard diamond tool (right) and with macle diamond tool (left).

Acknowledgments

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References:

[1] Hurlbut, Cornelius S.; Klein, Cornelis, 1985, Manual of Mineralogy, 20th ed.

[2] Kraus, Edward H.; Slawson, Chester B., 1939, Variation of Hardness in the Diamond, American Mineralogist **24** 661 - 676