A brief application of material parameters to predict polishing rates for optical glasses

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Abstract. This paper investigates the effects of material parameters of optical glasses on the polishing rate of these glasses. For this purpose, the material removal of various glasses was determined in laboratory tests under identical polishing conditions with respect to polishing pad and polishing suspension. The material removal was then evaluated for its dependence on material parameters. The goal of this paper is to derive a rule of thumb which allows an estimation of the material removal and the obtainable surface quality based on certain parameters of the workpiece material under comparable conditions. This rule of thumb can provide an initial insight into the polishability of a material and can be used to estimate polishing times and achievable surface qualities.

1 Introduction

The polishing of optical components is a complicated process step with more than 20 parameters. The single parameters are not independent from each other, which means that they partially interact with other parameters[1]. They depend on the glass to be polished, the polishing slurry, the used polishing pad, and the used machine parameters. Some parameters can be freely adjusted (within certain reasonable process- and machine limits), but many parameters are also defined by the used workpiece and it's mechanical and chemical parameters. For production planning, this represents a major challenge, for example in estimating process times and ensuring quality (roughness and defect sizes).

Existing models are often only applicable under laboratory conditions. The conditions between laboratory and optical shop floor often differ. For example, in the laboratory it is possible to work with small amounts of polishing suspension – in the industrial environment a central polishing suspension tank is usual. This influences the condition of the polishing suspension. For example, the polishing suspension can change during practical operation due to material that has been removed. In the laboratory, this can be solved by using smaller quantities and replacing the polishing suspension; in practice, replacing the polishing suspension too frequently would cause considerable costs.

This makes the use of empirical values in an industrial environment attractive. The disadvantage of this approach is a low flexibility in the case of for example, new types of glass or changed process conditions.

In this publication, we want to demonstrate the effects of certain material parameters of selected glass materials on the material removal rate (MRR) under otherwise identical polishing conditions. These constant conditions lead to a comparability of the polished components and the material removal. This provides the basis for a successful evaluation of the polishing tests.

2 Material and Methods

The experiments were carried out in the laboratories of the Deggendorf Institute of Technology using a synchrospeed polishing machine (Stock RSP 40). The polishing pad was a standard type GR-35 polyurethane material. A Hastilite-PO polishing slurry was used with a densitiy 1.025 g/cm^3. The polishing pressure p was 0.3 *Bar*, the velocity of spindle and pinole was 600 min^{-1}. Assuming the Preston equation[2]

$$dz/dt = K_P \, v_{rel} \, p,$$

it can be assumed that the MRR dz/dt is essentially determined by the Preston constant K_P, since pressure p and relative velocity v_{rel} are identical for all components. The Preston equation, in turn, is a measure of certain process-specific influences, including the influences of the glass material as well as influences from polishing slurry, polishing pad and environmental effects. By using otherwise identical components of the polishing process, influences beyond the glass materials could be minimized. The experiments of the several glass types where repeated several times to ensure a statistically underpinned result.

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Relevant parameters for glass materials are (among others):

- Glass transition temperature Tg,
- Coefficient of thermal expansion α,
- Resistance against water, acid and alkaline attacks,
- Heat capacity c_P

The used material parameters are standard parameters which can easily be found in the glass manufacturer's catalogue. Therefore, no complicated and expensive measuring devices are necessary for a successful use of the presented rule of thumb. Such an approach can also be useful in the optical shop floor for a rapid and successful process planning. Complicated integration of the properties of polishing agent, polishing substrate and machine parameters is (deliberately) omitted in this very basic model. Various glasses with quite different properties were examined. All glass samples have the same diameter of 30 *mm*, which allows the use of identical parameters for all samples and a simple calculation of the amount of removed glass material.

3 Results

The material removal was investigated by weighing the glass components before and after the polishing step. A cleaning step (ultrasonic and acetone C_3H_6O) was used to remove any remaining impurities, such as deposits of polishing agents or any fingerprints. The weight difference can be - under knowledge of the material's density and geometry - used to calculate the removed material and the MRR. Fig. **1** shows the material removal in *mm³*.

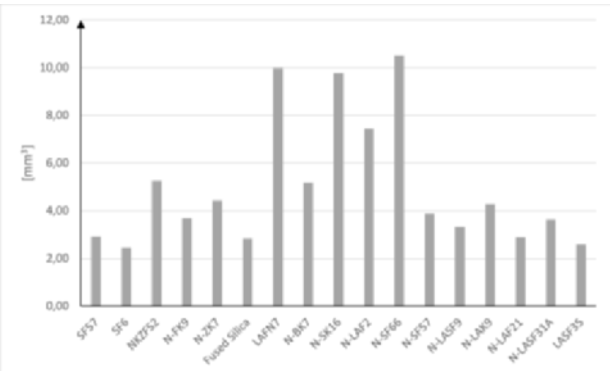

Fig. 1: Removed glass material in mm3. Variations between the removed volume and the removed mass are caused by the different density of the polished glasses. The error bars are not shown here.

The used glass samples have different chemical and mechanical properties. One opportunity is to separate the glasses in types with a low and with a high resistance against acidic attacks. Even tough glass is considered being resistant against acidic attacks (except for HF) acids can change glass surfaces. Over a longer period, this may well lead to a material failure. The acid resistance can be found in datasheets as the SR (1-53,3) value and is used according to standard ISO 8424 (describes the resistance of glass against aqueous acidic solutions at 24 *°C*[3]*)*. We have separated the values at a SR of 4. The SR values are not given here in detail but can be found as a standard material parameter in the datasheet.

4 Discussion and Conclusion

The goal of the research activity is the coupling of material removal to material properties. The benefit of this approach is, that a complicated process can be designed more deterministic. Furthermore, it is possible to obtain a faster optimization of the process by using a rule of thumb to find a good starting point for further optimizations.

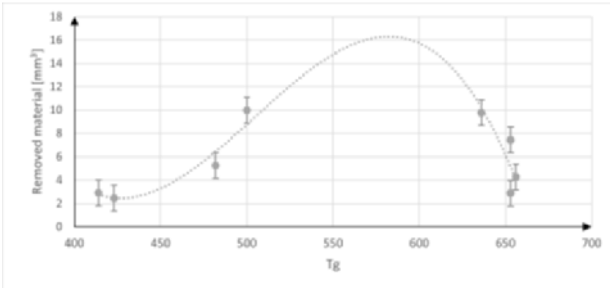

Fig. 2: Removed glass material in mm3 for glasses with low resistance against acid attacks as a function of the glass transition temperature Tg. The function shows a possible, theoretical course for a relationsip between Tg and material removal and has to be verified in further investigations.

Fig. **2** shows a dependency between the individual material parameters of the workpiece and the achievable material removal for glasses with a low resistance against acidic attacks. This relationship between material parameters is the basic for a rule of thumb to forecast material removal and surface quality of unknown or exotic glass types based on datasheet information. The goal of our research work is an industrial rule of thumb that allows an approximate estimation of the achievable material removal rate and the quality to be achieved in high-end polishing based on the glass data provided by the manufacturers. The presented research work is the basis for further research activities in the complicated environment of polishing high quality optical components.

References

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