# FUNDAMENTALS OF A NEW QUALITY RATING OF GRINDING TOOLS

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A common feature of the great number of methods developed thus far and actually applied for the investigation and evaluation of grinding tools is that they are both individually and as a whole unsuitable for an unequivocal classification. This is due in the first line to the fact that the methods of investigation little cope with the structural features of the tool. The wear of grinding tools built up from grinding grains and bridges of bonding materials exposed to great many stress alternations per sec imposes a *priori* to consider the individual bonds between bonding material and grain as factors determining the properties of the tool, at a difference from the macroscopic approach. Even this improved approach is far from being sufficient. The exact understanding of the essence of the structure and operation of grinding tools requires also to know the regularities in the microstructure of the tool. This mostly physicochemical and crystal chemical extremely complex problem involves marginal investigations.

The production of grinding grains, the formation of their microcrystalline structure, the distribution and the effect of their property-modifying components are known to be complex in themselves and not completely solved problems.

Understanding of the bond between the originally mainly crystalline later practically vitreous bonding material and the crystalline grinding grains developing in course of the production of grinding tools with ceramic bond is a complex of but partially cleared problems of how solid crystalline materials and high-temperature melts react.

Prior to presenting our experimental results let us summarize here our relevant findings and statements which served as an introduction to the fundamentals of the novel system of classification.

1. A systematic study of the microstructure of the grinding grains of electrocorundum and silicon carbide produced in various countries and factories, revealed a great variability in the quality, quantity and the distribution of the components in the microstructure of grains.

2. Varying the composition of the bonding materials and the firing procedure offers a precise control over the properties of the bonding layer formed at the phase boundary of the grinding grains and the ceramic bonding material during the firing process.

3. In the course of the formation of the bonding layer, the chemical composition and microstructure of the bridges of bonding material between grinding grains developing under various technological conditions was investigated by a great number of systematic, mainly electron optical measurements. The composition and microstructure of the bridges of bonding material were found to show periodical inhomogenities from the phase boundary of the grinding grain towards the interior of the bridges of the bonding material and the neighbouring grinding grain (electrocorundum grinding grains).

4. These periodical inhomogeneities can be interpreted by the complex theory of high temperature reactions between bonding material and grinding grains in solid and melt phase.

5. The up-to-date method of classification of grinding tools is based on correlations found between the microstructure of grinding tools developed under different and controlled technological conditions from various grinding grains and bonding materials and the E-moduli measured by a "Grindo-Sonic" instrument.

To develop an up-to-date method of classification of grinding tools and to produce grinding tools with predetermined properties the knowledge of the essence of processes taking place during the firing between the grinding grains and the vitreous bonding materials is necessary. No direct and concrete theoretical principles and data of literature are available in this respect.

The study of theoretical considerations and experimental observations described in connection with similar problems in other fields was of very valuable help in our work. In particular available studies in reactions of vitreous melts, slags and refractory oxides may serve in this field as a basis. The available data reflected little meritory research work in this field. Still, systematic presentation of the theoretical considerations and primary experimental results is felt to be useful in solving our problem and to stress the importance of the scope.

## Reactions between refractory oxides and vitreous melts

The bonding reactions between grinding grains of electrocorundum with vitreous bonding materials are similar to phenomena between the corundum-containing refractories of glass melting vats and the glass melts. Already quite number of experimental data are available in this field though the results escape exact explanation because of the complexity of the involved processes. When the scientists began to be interested in the empirically developed technology of glass they faced quite a number of problems accumulated and unsolved since centuries. These problems comprised e.g. the effect of composition changes on the properties of glass, and the interaction between melted glasses and refractory oxides. As the first step towards a scientific explanation of the empirical data the glasses have been compared with aqueous systems. In this field the concepts of acidity and basicity proved to be useful notions.

On the analogy of aqueous solutions, the glass components and the refractories later also the ceramic materials, glasses, enamels, slags and cements have been classified into acidic, basic and amphoteric oxides. Among ceramics, $SiO_2$ is a typical acidic oxide whereas the alkalies CaO and MgO are typical bases. Silicates containing excess $SiO_2$ are known to be considered acidic.

Unfortunately the concept acid-base is unsuitable in itself for the interpretation of the interactions between refractory oxides and glass melts. These high-temperature reactions are extremely complex processes. Their partial processes are tried to be explaned and interpreted by ionization potentials, electron affinity, ionic potentials, the concept of electronegativity and the polarity of chemical bonds. Still for the time being, even all the known theories are insufficient to solve given complex problems.

Reactions between refractory oxides and glass melts are often described as dissolution processes though they are fundamentally different. In case of glass melts and vitreous ceramic bonding materials the complex nature of their composition and the digestion of corundum leading to uncontrollable changes in composition make any theory or of any combination of theories useless for exactly characterizing the bonding process. Actually, this study will be reduced to importance likely of help in a stepwise, better understanding of the problems.

In studying the interaction of electrocorundum and the vitreous bonding material energetical or equilibrium conditions are more accessible than reaction rates.

The equilibrium conditions of ceramics are recapitulated in phase diagrams. From equilibrium aspects there is no oxide likely resistant to $Na_2O-CaO-SiO_2$ glass at its melting temperature. Quite independently of its kind the oxide will certainly be digested by the molten glass. The only problem is the rate of this process for various oxides, of importance also in our case. Reactions between melts and refractory oxides are hardly elucidated from this aspect. Whereas the investigation of equilibrium problems is facilitated by thermodynamics, no exact knowledge is available for the discussion of reaction rates. For the better understanding of problems of reaction rates connected with digestion processes (viscosity, screening, nucleation, hydration rate etc.) a socalled "screening" theory has been developed by E. C. MARBOE and W. A. WEYL. According to their definition an oxide is more acidic than another when it is screened by the $O^{2-}$ ions of the other (basic) oxide. Consequently, the $O^{2-}$ ions of the basic oxide are higher polarisability and stronger in screening effect.

The reaction between two oxides such as e.g.

$$2CaO + SiO_2 = Ca_2SiO_4$$

is explained by the mentioned authors as follows.

The cation $Si^{4+}$ present in $SiO_2$ can improve the screening effect by share its four oxygen atoms with the $Ca^{2+}$ ions rather then with other $Si^{4+}$ ions. Another interpretation of the same reaction is that oxygen ions of CaO and $SiO_2$ are of different polarizabilities and they react with each other to balance the polarization states of their oxygen ions. On this basis in a given case it may safety be expected that e.g. silica sand is digested in glass since the $Si^{4+}$ ions in the glass are better screened than in the quartz crystals. Similarly, also CaO is dissolved in glass when its oxygen ions improve the screening of the cations in the melt.

In the case of corundum (as an amphoteric oxide) this problem must always be solved by way of experiments.

In reactions between refractory oxides and glass melts also galvanic processes take place. Digestion is accelerated when electrons migrate from the glass into the refractory oxide.

Glass technologists have long been aware of reaction zones in borosilicate glasses with an alkali content beyond the overall level. In other cases, the concentration of some oxides has been observed to essentially change in the direction of e.g. glass melt-refractory material. For instance the concentration of CaO and BaO decreases quicker than that of $Na_2O$, and $Na_2O$ penetrates deeper in the refractory oxide than the former ones. This phenomenon can be explained by the higher mobility of $Na^+$ ions carrying only one charge. It was rather curious to observe that the overall concentration of $K_2O$ at 6% in an analyzed glass was as high as 9.6% at the phase boundary of the refractory oxide and the glass melt. This finding was the more interesting because $K^+$ ions are much greater than $Na^+$ ions. This phenomenon is explained by WEYL by the different screening capabilities of the two ions. For instance, in case of a corundum vat lining $K^+$ ions migrate nearer to the reaction zone and penetrate into electrocorundum at a higher rate because of their higher capability of screening.

$Al_2O_3$ requires screening and thus it attracts the oxygen ions of the glass melt. The capability of screening of oxygen ions depends on the nature of polarizing cations. $K^+$ ions of lower field intensity are more suitable for screening than $Na^+$ ions.

Similar phenomena occur in geochemical processes where the migration processes of the individual elements can be ascribed to similar factors.

In separating $K^+$ and $Na^+$ ions in chromatographic columns, the $K^+$ ions are known to be stronger bound by the adsorbent than $Na^+$ ions. The same processes occur at large scale in nature, e.g. when rocks containing both sodium and potassium are weathering only the $K^+$ ions are retained in the soil whereas the $Na^+$ ions migrate into the oceans.

In high-temperature reactions, the viscous flow of vitreous melts is not always dependent on the fission of the existing chemical bonds, but may be induced by the temporary increase of the individual cation-anion distances, at a screening loss. Viscous flow can also be described by the temporary change of the co-ordination number. For instance even silica glass can flow if thermal energy required by silicon ions to change their co-ordination number from 3 to 4 is available. Obviously more energy is required than to change the cation co-ordination number from 5 to 6. Again $Al_20_3$ and $Zr0_2$ are known to diffuse extremely slowly in soda-lime glass of a co-ordination number four whereas they fit well in the octahedral co-ordination. The liquid state of an oxide system can be realized as if the anions and the cations are freely exchangeable in the systems with anionic and cationic lattice respectively. The fact that one cation is of octahedral and the other tetrahedral co-ordination, prevents them from mixing in either solid or molten state except when oxide system contains highly polarizable cations (e.g. $Pb^{2+}$ or $Ba^{2+}$) or polarizable anions (addition of $K_2O$). In this case tetrahedral and octahedral polyhedrons can be mixed. This is actually the prerequisite of homogeneous glass to form, and an essential factor of dissolution and diffusion processes. Therefore the co-ordination number of cations is of major importance in digestion processes.

## Processes between of electrocorundum grinding grains and bonding material melts

To test the high-temperature bonding reactions between electrocorundum grinding grains and ceramic bonding materials, the melt of borosilicate bonding material, the same as applied for the production of grinding tools, were allowed to react with electrocorundum grinding grains for various periods under identical conditions. After freezing the reactions, the changes in the chemical composition and the microstructure of the grinding grain-bonding material system were examined with electron optical methods. The chemical composition changes at the phase boundary of the grinding grain and the bonding material and in its environment has been traced by measuring the intensity of the characteristic elements of the grinding grain and the bonding material. Great many measurements have been made on grinding grains-bonding materials samples undergoing reaction for various periods. The progress of the intensity of aluminium, potassium and silicon along straight lengths of about 100 $\mu$m was measured stepwise, passing from the grinding grain towards the bonding material.

According to coincident data of parallel measurements the intensity of aluminium decreases abruptly at the border of the grains then further in the bonding material, and the average concentration value typical of that bonding material comes about along curves varying for each sample. Intensity changes of potassium and silicon are of the same character as aluminium but of the opposite sense.

The slopes of the concentration changes in the bonding layer vs. reaction time are shown in Fig. 1. Fig. 1 demonstrates the nature of the concentration changes of aluminium, potassium and silicon to be practically of the same trend.

In summarizing the measurements results plotted in Fig. 1, three typical concentration curve shapes have been distinguished the characteristic values for aluminium are represented in detail. Fig. 2 exhibits the aluminium intensity variations from among maxima in Fig. 1, whereas some typical minima are

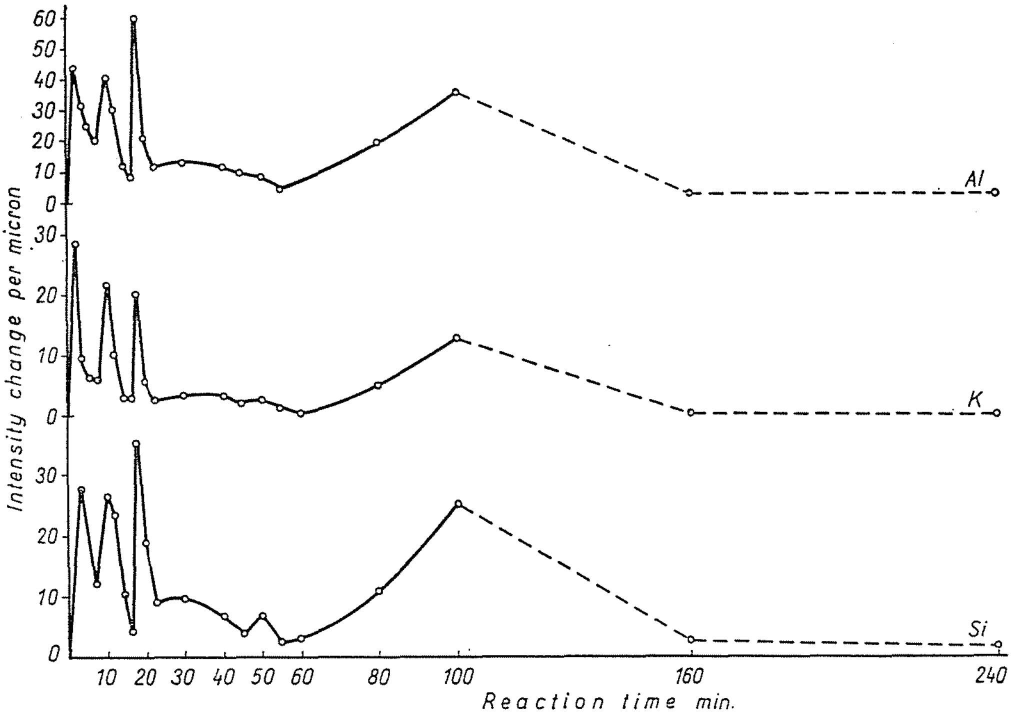

*Fig. 1.* Slopes of the variation of concentration of some typical elements of grinding grain and bonding material in the transition layer vs. reaction time

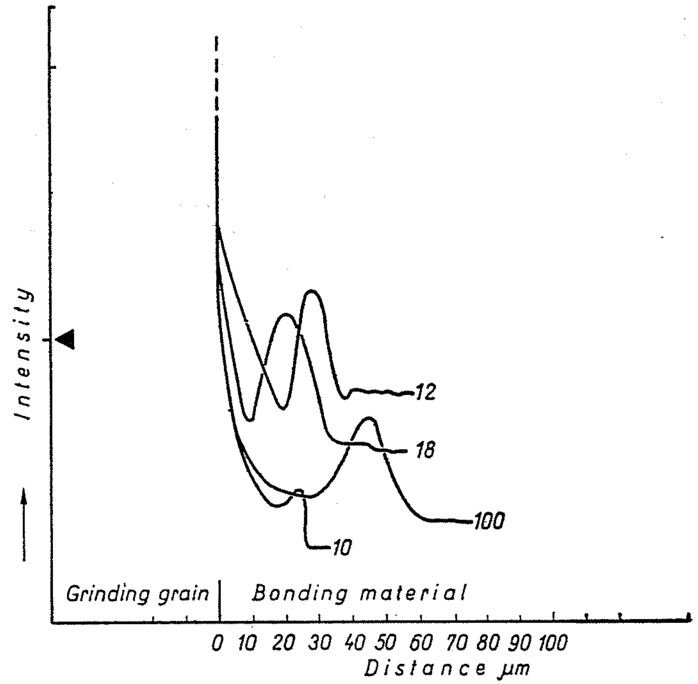

*Fig. 2.* Aluminium intensity variation in the environment of the phase boundary between grinding grain and bonding material for various reaction times

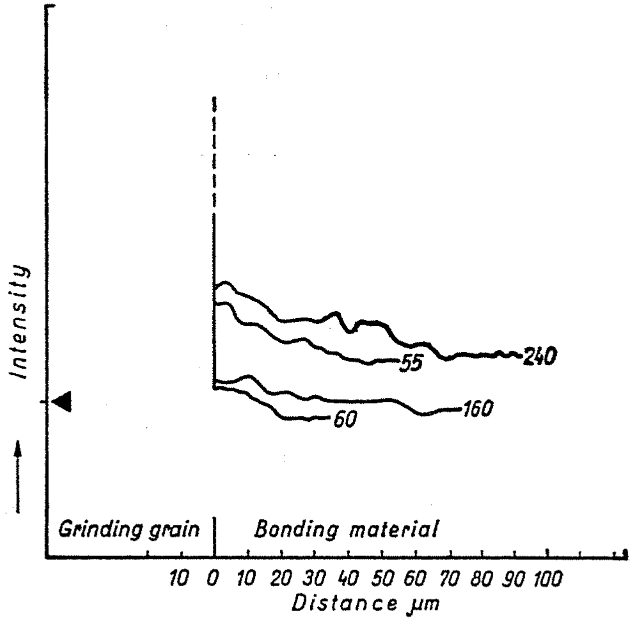

*Fig. 3.* Aluminium intensity variation in the environment of the phase boundary between grinding grain and bonding material for various reaction times

shown in Fig. 3. As an example some curve shapes concentrations intermediate between maxima and minima are given in Fig. 4.

Since in our earlier relevant investigations a typical correlation could be established between the bonding processes and the moduli of elasticity of grinding tools prepared under identical conditions, our research has been completed by determining the moduli of elasticity. A great number of grinding tools were produced with a technique practically identical with the experimental conditions of the reactions between solid and melt phases. The composition of these grinding tools was identical throughout: the samples differed only by the conditions of firing. The development of the E-moduli of these grinding tools was examined by a Grindo-Sonic instrument, data being shown in Fig. 5.

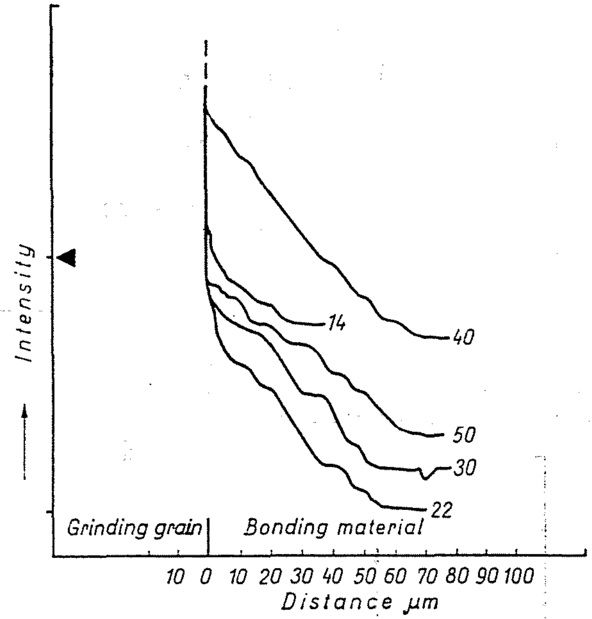

*Fig. 4.* Aluminium intensity variation in the environment of the phase boundary between grinding grain and bonding material for various reaction times

A confrontation of the variation in the chemical composition of the transition or the bonding layer with the development of the E-modulus points immediately at very striking, unequivocal analogy. The analogy between the typical variations of bonding layer and E-modulus is felt to be in a close correlation with the microstructure and, with its alterations under various conditions of reaction (firing) in agreement with our repeatedly reproduced tests. Figs. 2, 3 and 4 show microstructures exhibiting similar changes in their composition to form periodically upon varying the reactions times (technological conditions). Microstructures of identical character formed during various reaction times differ percentage intensities of components. In the figures, the identical levels of intensity are denoted by black triangles. The unequivocal analogy between the characters of both values and curves seems to support our initial statement that features and alterations of the grinding tools are inherent to the individual grain to bonding material bonds. The bonding reactions in the individual grinding grains to bonding material systems and the developing microstructures are characteristic enough to feature the grinding tool built-up from a great number of grains. This finding is fundamental to the novel system of classification now under development.

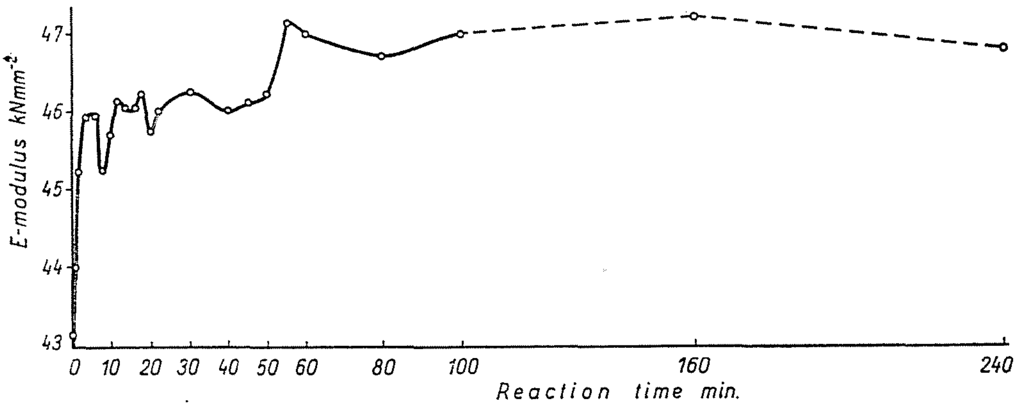

*Fig.* 5. Development of the moduli of elasticity of grinding tools of identical composition and prepared under the same conditions as the model substances (Figs 1 to 4) vs. firing time

The essence of the novel system of classification is that the elasticity modulus of the bonds with bonding materials of known fundamental properties formed under various technological conditions is a predictable characteristic, and E-moduli of grinding tools prepared under unknown conditions can be evaluated in an indirect way in the knowledge of the above mentioned data.

This is a vast program of research and systematization. For the actual evaluation of the E-moduli it is of fundamental importance to correlate their numerical values to grinding achievements.

The outlined program is already in progress, completed with the experimental use of grinding tools produced under pilot-plant conditions.

## Summary

For the sake of developing an up-to-date system of classifying grinding tools from its fundamentals complex work has been carried out to establish the nature of the bond between the examined grinding grains and bonding materials of various qualities to correlate it to the microstructure of grinding tools developed under controlled technological conditions and to the moduli of elasticity determined by a "Grindo-Sonic" instrument.

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