Consolidation Behaviour of SiC Ceramic Composites

S.S.Abdulnoor* , Y.K.I.Al- Ani ,M.G.Yousif
Department of Physics , College of Edoucation ,Ibn AL- H aitham ,University of Baghdad
Department of Applied Sciences,University of Technology

Abstract

Three composite grinding wheel series were prepared using three different ceramic binders . Two of the three series behaved in typical ceramic – type manner in their consolidation behaviour , while the third deviated strongly . The measured mechanical properties behaved in a similar manner . The main reason was found tobe the way the binder material interacts with the SiC – particles . The results are discussed in terms of the rol played by the binder in shaping the final mechanical properties of the composites .

Introduction

Cutting and grinding are among the major processes which the industry have always depended upon throughout it's history . Grinding and finishing materials had also to be developed in order to cope with every changing needs of the industry . Such materials have to be tough and offer along service life in addition to their performance, in order to be economically feasible . Grinding wheels belong to this category of materials and they also constitute a sizeable industrial production field (1). They are manufactured of various abrasive materials and made up to various specifications standardized for various applications . As a ceramic body , the SiC- grinding wheel is formed and consolidated using the liquid – phase sintering mechanism (2). This would in fact make the process of selecting or developing the binding material an important factor in deciding the final quality and performance .In addition to that there are other ceramic parameters which may also reflect upon the final efficiency of the wheel . Barry et.al.(3) investigated the effect of the type of grinding particle on the mechanical strength of the grinding wheel . Johnson (4) later studied this effect upon the wear behavior of the ceramic .Where as

,Hisakada(5)on the other hand investigated the effects of residual stresses. in tile bulk of ceramic on its final grinding performance. Others (6,7) , investigated the effects of the high rotation speeds of the wheel as safety requirement. The present work aims at studyingthe consolidation behavior of SiC- grinding wheels as a composite containing defferent types of ceramic binding materials. It is also meant to investigate the effect of the binder on the final mechanical properties of the SiC – ceramic composites .

Materials and Methods

SiC- powder was ground and classified prior to sample preparation , moreover it was tested by X- ray diffraction for the cubic phase singularity . Three types of ceramic binders were used (glassy binder 1) and two ceramic binders (2,3) , their constitutions are detailed in table –I (8) . The three binders were ground and classified to the desired barticle size, which was of the sameorder as that of the SiC. Both powders (SiC and binder)were properly mixed in a ball mill for 24hrs. The resulting homogeneous mixture was then pressed into the shape of a grinding wheel. The green compacts werethen sintered at temperatures of 1000-1300° C for various time intervals ranging between 25 minutes and 4hours. Density measurements weremade by the immersion method , which also allowed the determination of porosities for individual specimens. Rockwell hardness of individual specimens was measured using a primary load of 10 kg. And a main load of 60 kg., and the ball shaped identre was 1/8 inch in radius . The Young moduli of all specimens were deduced from Knoop – micro-hardness values , using the formula suggested by Marshal et.al.(9).

$$\frac{b'}{a'} = \frac{b}{a} - \text{œ} \frac{H}{E}$$

H= Hardness

E=Young modulus œ = 0.45, a, b ,a, b =radii

The impact strength of all specimens was measured by the Charpy pendulum using un notched specimens .

Results and Discussion

Silicon carbide compacts were formed using three different ceramic binding media, the compositions of which are listed in table-

1. The amount of the added binder was found to be rather critical , since when exceeded a certain percentage it reflected negatively upon the final ceramic composite the optimumpresence of the binder –1 was found to be 5%, since those containing about 10% binder were deformed . However, the other two binders were added in two percentages (5% and10%) without deforming the specimens . The compaction behavior of the composite specimens is shown in fig. (1), and that of the porosity in fig. (2) All the three series (glassy binder–1and ceramic binders-2,3) exhibited a typical ceramic sinterability . However, there were some individual differences in the rates of consolidation , which is basically dependent upon the nature of the binding liquid phase (molten glass or ceramic). The surface tension of the melt is expected to play a major role in the diffusion process of the molten binder throughout the ceramic matrix . Also ,the wettability between the SiC- particles , and the molten binder , is expected to play –just as an important role in the above mentioned diffusion process. In fact, these mechanisms are expected to compete among themselves , where the surface tension tends to hinder the diffusion whereas the wettability (the adhesion –forces between the melt and the particles) tend to encourage the diffusion . Series-I(glass binder) exhibited a higher saturation density value as compared to those of the other two series . suggesting that the dominance of the wetting adhesion – forces is much more explicit in series –I. The enhanced diffusion of the molten binder would lead to a superior densification behaviour. The final values of porosities remnant in the bulk of all the three series were ranging between 30% and 36% which falls well within the industrially accebted specification for grinding wheels .The hardness is a surface mechanical property , which is very closely related to the performance of grinding wheels .It may reflect their resistance to scratching and wear . The hardness of all specimens were measured and plotted in fig.(3), as a function of sintering time of the SiC – composites. It may be noticed that series –I and Iibehaved in a manner typical for a ceramic , since it imaged the densification process shown in fig.(1) quite explicitly . Reflecting that the material has reach ed its ultimate state of consolidation (i.e.mechanical strength), However , series III deviated from the above behaviour by exhibiting a bell-shaped curve , which may be due to instabilities in the diffusion process of the melt . Thus , suggesting that the molten binder – I and II diffused much more efficiently than binder-III .The wetting

adhesion - forces seem to dominate over those arising from the surface tension of the melt . Also suggesting that the surface tension forces are much more effective in series III, where the diffusion process had been effectively hindered .An optical microscopic test (8) made on these specimens clearly indicated a high concentration of the binder at the center core of the material . This confirmed the suspected poor binder homogeneity caused by the tendency of inward-migration of the molten binder towards the core. Thus , longer sintering periods would lead to a greater inhomogeniety and binder segregation . The peripheral regions would then suffer from binder deficiency and poorer consolidation. This would most definitely reflect negatively upon the mechanical strength . The impact strength of the three series is shown in fig.(4) as a function of sintering time . Similarly , series – III differed from the first two series by exhibiting a bell shaped curve . Whereas series –I and II behaved in a smooth rising manner . This inconsistency is also due to the remnant inhomogenieties previously diagnosed in series-III, which may result in an earlier failure.

Young modulus values deduced from knoop microhardness measurement(9) are plotted in fig .(5) as a function of sintering time . Similarly , series I and II behaved in normal saturable (ceramic – type) manner , whereas series III deviated explicitly . The Young modulus of series III increased to a maximum value then dropped rather smoothly . This conforms with the previously discussed behaviors shown in fig.(1-4) . From what has been exhibited above , one may conclude that the actual mechanical strength of ceramic grinding wheels stemed mainly from the mechanical nature of the binder material . In spite of the fact that the grinding action is mainly undertaken by the SiC – particles. In fact, the binding material forms an infrastructure which holds the abrasive particles . Moreover , this infrastructure offers a stiff mechanical support to the abrasive particle throughout the ploughing process. The binding infrastructure has to overcome most of frction resistance exhibited by the work – piece material . This may be confirmed by the observed difference between the three series , which only differed by their binders, and the way they interacted with the SiC – particles.

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Table(1) Different binding media of ceramic origin

Elements%	Binder1	Binder2	Binder3
SiC_2	70-75		29
Na_2O	12-18		
K_2O	0-1		
CaO	5-14		
B_2O_3			1
Al_2O_3	0.5-2.5		
MgO	0-4		
$Al_2Si_2O_5(OH)_4$		40	
$NaAlSi_3O_8$		40	61
$CaCO_3$			5
K_2Co_3			2
Na_2Co_3			2
GLASS		20	

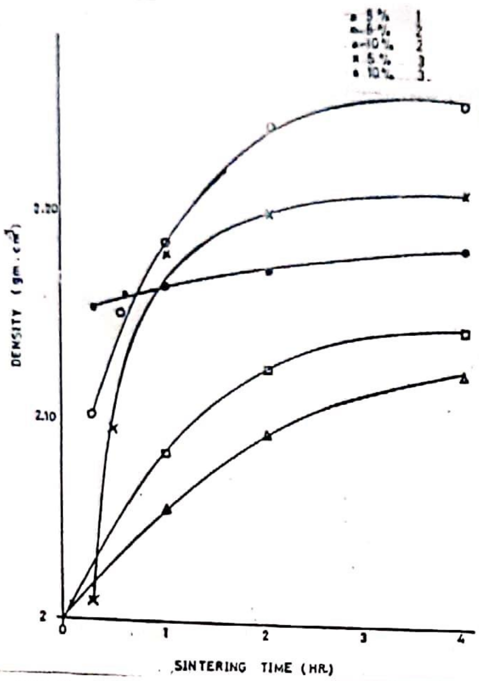

Fig. (1) Variation of density with sintering time

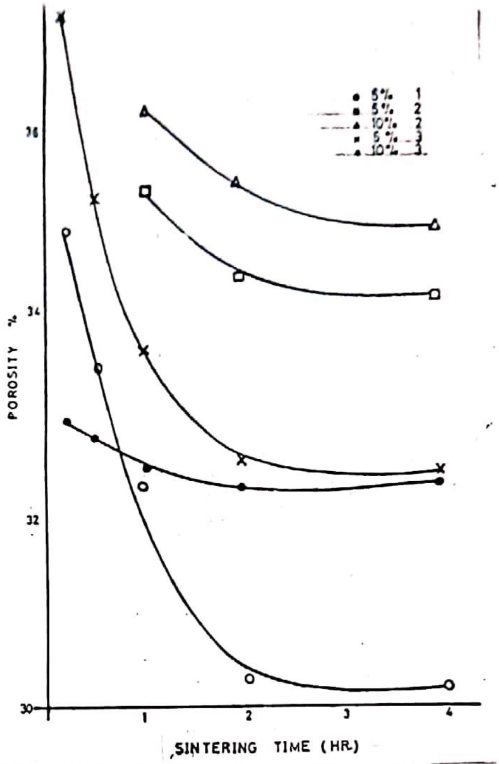

Fig. (2)Variation of porosity with sintering time.

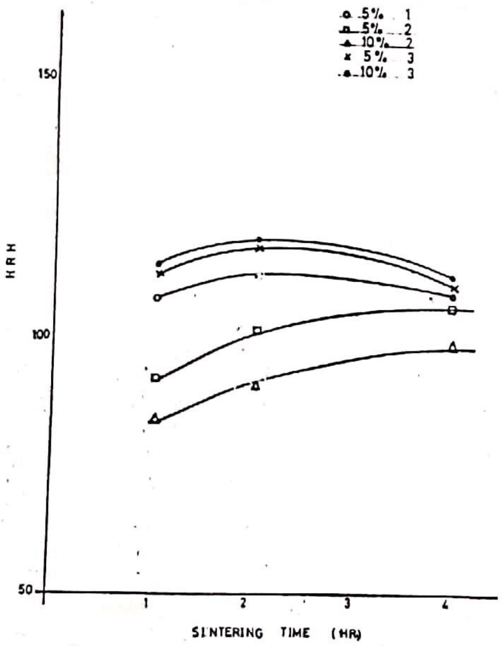

Fig. (3) Variation of hardness with sintering time.

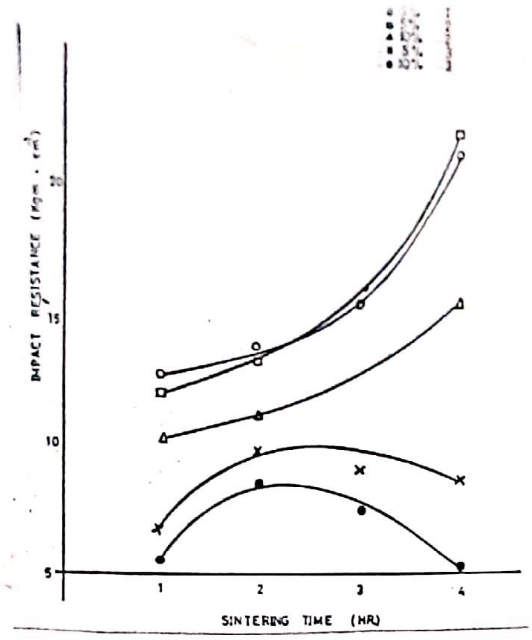

Fig. (4) Variation of impact resistance with sintering time.

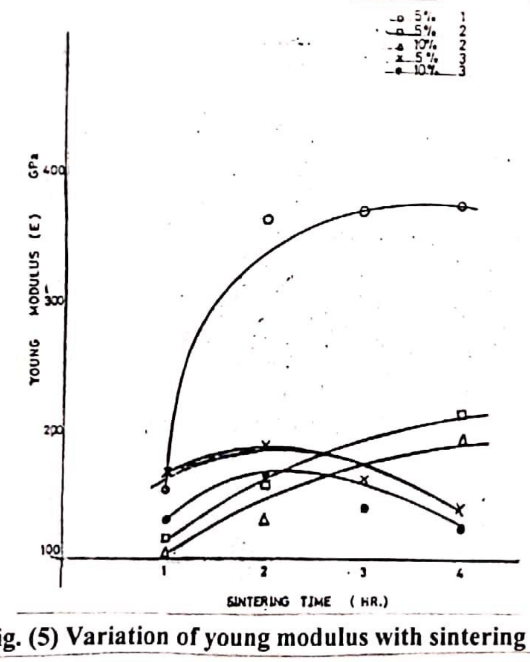

Fig. (5) Variation of young modulus with sintering time.

سلوكية الرص لسيراميك كربيد السيلكون المركب

صباح عبد النور، ياسر خليل ابراهيم، مؤيد جبرائيل يوسف
قسم العلوم التطبيقية، الجامعة التكنلوجية
وزارة العلوم والتكنلوجيا
قسم الفيزياء ، كلية التربية ابن- الهيثم

الخلاصة

حضرت ثلاث متسلسلات من اقراص التجليغ المصنعة من مادة كربيد السيليكون المخلوط مع ثلاث انواع مختلفة من المواد الرابطة . وبقدر ما يتعلق الامر بسلوكية الرص السيراميكية فقد سلكت اثنان من هذه المتسلسلات سلوكية سيراميكية مثالية بينما حادت المتسلسلة الثالثة عن ذلك . وقد اظهرت نفس المتسلسلة هذه حيود كبير في خواصها الميكانيكية عن المسلسلتين الاخرتين اعلاه . ووجد بأن العامل المؤثر الرئيس في تحديد السلوكيات اعلاه هو كيفية تفاعل المادة الرابطة مع دقائق مسحوق كربيد السيليكون .ونوقشت النتائج المستحصلة في ضوء الدور الذي يلعبه هذا التفاعل في تشكيل الخواص الميكانيكية النهائية للاقراص المركبة .