Mechanical Strength of Alumina Compacts Lubricated with Poly (methacrylic acid esters) Copolymers

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Abstract

In recent years, there has been a rapid development in research on high performance ceramics for mechanical, electrical and medical industries. This development will be shown for alumina as a representative for oxide ceramics powders.

Dry–pressing forming technique was used to prepare different ceramic compacts for alumina grafted by polymethacrylate polymers. All Alumina compact were fired firstly at 1200 °C, then at 1600 °C.

Mechanical strength was examined in different means, some depends on compression and other depends on impact. Hardness was also measured .The results obtained were compared with that of Alumina compact prepared under the same condition from Alumina especially made for pressing .

The results revealed that the compacts lubricated with polymethacrylate copolymers had higher mechanical properties than that prepared from Alumina made especially for pressing, reflecting the good capability of those polymers to act as lubricant for Alumina particles, this was supported by scanning electron microscope.

Keywords
Alumina, Lubricants mechanical strength

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المتانة الميكانيكية لمكبوسات آلومينية مزيتة بواسطة بولي(استرات حامض الميثاأكريليك)

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الملخص :

حصلت تطورات سريعة في مجال بحوث استخدام السيراميك الفائق الدقة في معظم المجالات التطبيقية منها الميكانيكية ، الإلكترونية والطبية. وفي هذا البحث سيتم التعامل مع مكبوسات الألو مينا كمثال للمساحيق السيراميكية الأوكسيدية.

شكلت الألو مينا المطعمة بالبوليمرات الميثاأكريليتية (كمادة مزيته للجسيمات السيراميكية) بطريقة الكبس الجاف لتحضير مكبوسات سيراميكية، حرقت النماذج أولاً عند درجة حرارة 1200°م ولبدت بعدها عند درجة حرارة 1600°م .

فحصت المتانة الميكانيكية بعدة طرق منها ما يعتمد على الانضغاط والأخرى على الصدمة ، وكذلك قيست صلادة المكبوسات الألومينية المصنعة ، قورنت هذه مع مكبوسات ألومينية ناتجة من ألومينا خاصة بالكبس . فكانت الأولى أفضل بكثير من الثانية معطية الانطباع على القابلية الجيدة للبوليمرات الميثا أكريليتية للعمل كمادة مزيته للمساحيق السيراميكية. دعمت النتائج بالفحص المجهري للنماذج باستخدام المجهر الإلكتروني الماسح .

Introduction

The field of ceramic materials is extremely fast and varied. This holds for compositions and forms, as well as for properties and applications. An extraordinary variety of special ceramics has been developed during the last decades, which has found applications in many areas of industry and research. Depending on the intended applications, these special ceramics may be classified into four principal groups, i.e. Ceramics for electronic, optical, nuclear and structural applications [1].

Alumina (Al_2O_3), can be considered as typical representative of the structural ceramics group, beside some other oxide ceramics such as titania (TiO_2) zirconia (ZrO_2) , magnesia (MgO) and its mixes with alumina like alumina–magnesia spinal ($MgAl_2O_4$) , … etc [2]. These ceramics are intended particularly to serve as structural parts subjected to mechanical loads, in many cases at high temperature. Alumina (Al_2O_3) is an extremely useful ceramic in many existing and emerging technologies. These include bio-medical implants, High density in alumina components is normally achieved by sintering compacted alumina powder above 1600ºC [3]. The main function of these materials is to sustain mechanical loads. Thus, the common feature of structural ceramics is good mechanical behavior and, therefore, efforts in developing, fabricating, and optimizing these materials are mainly concentrated on the aim of high strength. In many cases the development of high–strength ceramics is carried out with the objective of substituting metallic materials [1].

The final strength, uniformity and quality of the fired ceramic are believed to be very dependent on achieving good particle packing in the green state[4]. Copolymers of n-butylmethacrylate/ methacrylic acid were proved to have good ability to act as binders for alumina particles during dry. Pressing technique of forming, this was reflected on their excellent physical properties, such as bulk density, apparent solid density, true porosity..etc [4]. This was attributed to their effective lubrication for alumina powders during the applied load of pressing. This has encouraged us to carry on testing their mechanical properties in the current work.

Experimental:

1) Materials:

Alumina powder lubricated by block and random copolymers of n-butyl methacrylate/methacrylic acid was obtained by grafting in colloidal phase as described elsewhere [4,5].

Ready-made alumina especially for pressing was also used as reference it was purchased from Alcan of England.

2) Mechanical Properties:

The investigation of mechanical properties of samples was essential for their use in various applications. The fracture strength in compression and impact and hardness are among the primary properties examined.

(i) **Brazilian Disc Fracture Test**

This type of test is commonly used when conventional tensile is difficult to carry out due to the brittle nature of the test material [6].

This test was performed on fired discs having about 21 mm diameter and 4mm height; using compression test device Instron1195.The samples were fixed between upper and lower plates to start compression at a rate of cross-head speed 5 mm / min until failure. The value of fracture strength δ_f can be calculated by [6]:

$$\delta_f = \frac{2F}{\pi dh} \quad \text{.............................} \quad (1)$$

Where

F is the applied load (N), d is the sample diameter (m), h is the sample thickness (height) (m).

(ii) Impact Strength Test

The impact strength was measured by Izod system according to the following equation [7]:

$$W_n = \frac{G.L(\cos\beta - \cos\alpha)}{A} \quad \text{............} \quad (2)$$

Where,

W_n is the impact strength (J/cm^2), G is Pendulum mass (2.356 kg), L is Pendulum arm length (0.382 m), α is angle of pendulum before striking (constant degree), β is angle of pendulum after striking, A is cross- section area of sample (m^2).

(iii) Hardness

It was measured after the samples passed grinding and polishing processes. The prepared specimens were tested with Vickers indenter attached to Wilson/Rockwell hardness series 500 made in U.K. The indentation load was chose to be 15 kg for 60 sec., across diagonal and the formed of cracks length of Vickers impression were measured by the aid of leitz optical microscope (model leitiz Germany).

The Vickers hardness number (H_v) is the ratio of load applied to the identer to the surface area of the indentation [8].

$$H_v = \frac{2P\sin(\frac{\theta}{2})}{D^2} \text{ (Kg/mm}^2\text{)………. (3)}$$

Where, P is applied load (kg), D is mean diagonal of indentation (mm), θ is the angle between opposite faces of the diamond (136 º).

The Knoop hardness H_k is the ratio of applied load to the indenter to the unrecovered projected area [8, 9], and it's given by:

$$H_k = \frac{P}{A} = \frac{P}{Sd^2} \text{ …………............ (4)}$$

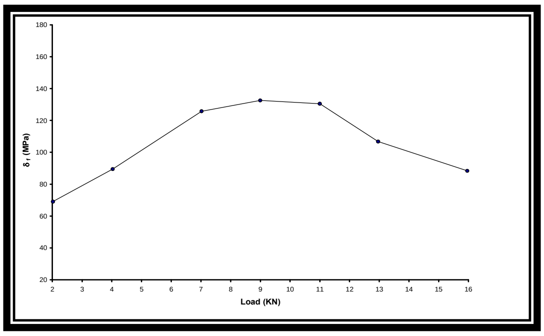
Where, H_k is knoop hardness (J/cm^2), P is the applied load (kg), d is the unrecovered projected area of indentation (mm), S equal to 0.0708, is constant for the indenter relating to projected area of the indentation to the surface square of the length of the long diagonal.

Results and Discussion

All mechanical tests were carried out on alumina ceramic bodies in the fired state in the form of discs made by dry – pressing forming technique.

Examining the results obtained from diametrical compression strength (δ_f) for ceramics pressed under different loads for alumina especially made for pressing shows that the load 9 kN produced ceramics which had the higher strength among others, Fig. (1). This was attributed to the better density and lower level of porosity and may not have any internal cracks because of higher pressing load [10,11]. Decreasing of diametrical compression strength after load of 9 kN was related to the presence of some internal cracks. This was confirmed by examination of the specimens by SEM.

Fig.(1): Effect of pressing load on diametrical



compression strength of alumina especially made for pressing

Obvious differences can be seen between ceramic produced with each particular lubricant, especially between the two types of alumina used, i.e. ready – made alumina and that grafted with random and block copolymers. This must be related to homogeneity of the discs, arising from the better quality of lubrication. Alumina compact lubricated with random copolymer higher diametrical compression strength than, block copolymers, and both produced better strength than the ready-made alumina, which were in good agreement with their physical properties studies [10]. Further evidence for better diametrical compression strength and better compacting came from SEM examination of the smooth surface and fracture surface, Fig. (2b) and (2c), which confirms the better lubrications of alumina particles is obtained with the copolymer lubricants comparing to those of alumina especially made for pressing, Fig. (2a).

Dynamic fracture occurs under rapid load called impact. This was calculated according to equation (2). Fig. (3), illustrates the results obtained from alumina compacts made especially for pressing at different loads. The load 9 kN is appeared to be the best among others. The decreasing of the impact strength after this pressing load may be attributed to the presence of some internal cracks in the species as shown by SEM micrographs, Fig. (4), which may led to rapid propagation of cracks by effects of pendulum strike which causes reduction in its impact strength.

Ceramic made from alumina lubricated with random copolymers gave better impact strength than those lubricated with block copolymers, and both are better than ceramics obtained from alumina made especially for pressing, Table (1). This reflects the high packing of alumina particles in these compacts, which can be seen very obvious in SEM micrograph, Fig. (2).

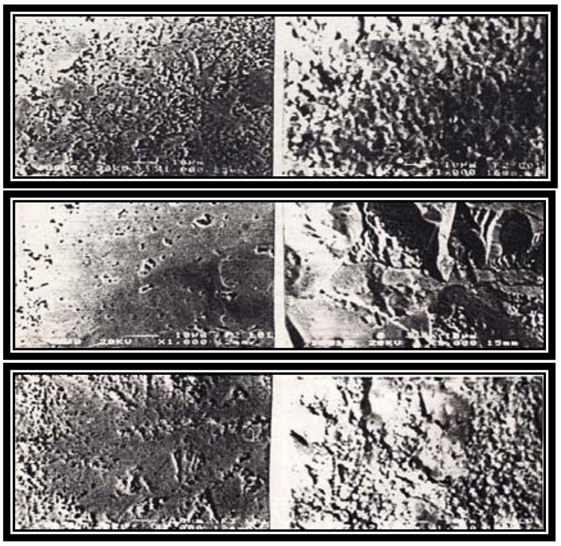


Fig.(2): SEM micrograph of alumina for structure of surfaces and fracture region at load 9 KN:(a) alumina made especially for pressing, (b) alumina grafted with random copolymer; (c) alumina grafted with block copolymer

Table (1): Mechanical properties of different alumina compacts pressed under 9 kN and fired at 1600 ºC

Mechanical Property	Symbol and Units	Type of Lubricants		
		Ready-Made Alumina	**Block copolymers**	**Random copolymers**
Compressive Strength	δ_f , MPa	132.506	146.800	151.160
Impact Strength	Wn , J/cm^2	34.379	42.352	43.667
Vickers Hardness	H_v, GPa	16.599	20.84	22.02
Knoop Hardness	H_k, GPa	17.534	21.60	23.21

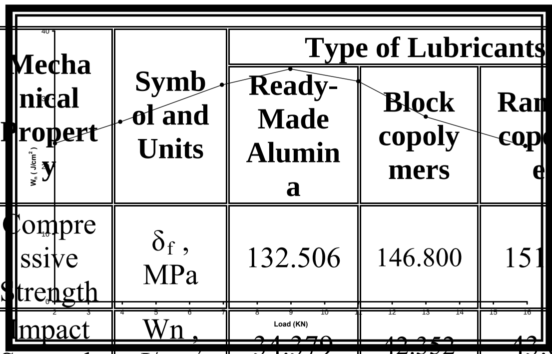


Fig.(3): Effect of pressing load on impact strength of alumina especially made for alumina.

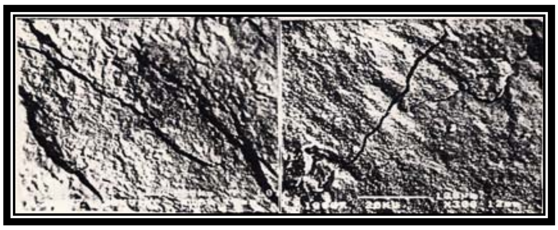


Fig. (4): SEM micrograph of alumina compacts made especially for pressing at load more than (9 KN).

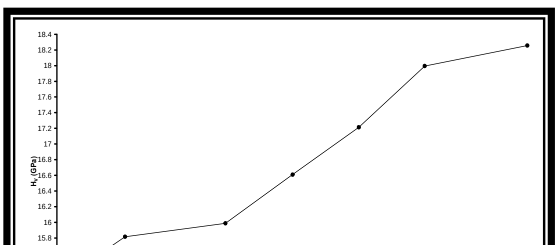


Fig (5): Effect of pressing load on Vickers microhardness for alumina especially med for pressing.

Since hardness is one of the best properties owing an indication of the ability of materials to resist scratching, abrasion or penetration. Vickers and knoop micro hardness test was performed on the different types of polished alumina specimens as mirror.

The effect of pressing load on Vickers and knoop hardness for alumina especially made for pressing is shown in Fig. (5), which exhibits that increasing the pressing load leads to an increase in Vickers and Knoop values. Examining the hardness of ceramics lubricated with random and block of n-butyl methacrylate /methacrylic copolymers revealed that the higher values obtained with former copolymer and both are much better than that of ready made alumina, Table (1).

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