ISSN 2229-5518

Impact Fatigue Behaviour of fully dense Alumina Ceramics with Different Grain Sizes

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Abstract: Impact fatigue behavior of fully dense alumina as we studied in this work. The effect of grain size on the impact fatigue characteristics has been found out using a simple impact fatigue test set-up. Low grained alumina was prepared using optimized slip mcasting technique where as higher grained samples were made following conventional powdered metallurgy technique (Compaction through isostatic pressing and subsequent solid sate sintering. All though the mechanical behavior (e.g.hardness, toughness) was better in fine grained alumina, It was more succeptable to impact fatigue. Some of the sampled in higher grained alumina samples were little bit elongated in shape with aspect ratio close to 2-2.5. Fractoghaphy revealed that crack propagation was predominantly mixed mode. The elongated grains promoted bridging across crack front and caused higher resistance to fatigue.

Index Terms— dynamic, element, factor, finite, impact, intensity.point, quarter, stress

1 INTRODUCTION

OWING to high hardness, compressive and extremely ly good corrosive resistances alumina is one of the mostly used turbo materials. In last few decades few few of studies have been done on the dependency of grain size on impact fatigue behavior of alumina.B. K .Sarkar and T.G.J Glinn (1969) studied the impact fatigue of an alumina ceramic and exhibit fatigue behaviors, having a high stress plateau followed by progressively increasing endurance with decrease in applied impact energy. S Maity and B.K.Sarkar (1994) studied the impact fatigue of a porcelain ceramic and showed a definite fatigue behavior with increasing endurance in decreasing impact energy levels and cumulative residual stress is suggested to explain the fatigue behaviors. S. Maity, D. Basu and B.K. Sarkar (1994) studied the fatigue behaviors of fine-grained alumina under repeated impact loading and found that the fatigue resistance parameter is 17.12 while the endurance limit is around 270Mpa which is about 38% of the single impact strength of the material and also found that fatigue cracks are trans-granular near the crack initiation region, the rest being inter-granular. Manabu et al (2002) studied the material response to particle impact during abrasive jet machining of alumina. A relatively smooth face can be produced when silicon carbide (GC) abrasive is employed.

The fatigue behaviour of fine-grained alumina hip joint heads under normal walking load has also been reported by Basu et al (2005) and found that the alumina femoral heads have successfully withstood 10^7 cycles at maximum walking stress of 17.2 KN, which is equivalent to a body weight of 400Kg. The femoral heads didn't exhibit any sub-critical crack growth at the maximum walking load of 10KN, indicating the quasi-infinite performance life in-patient up to body weight of 250 Kg.

In recent past as new grade of alumina powder is available with very small particle size and new processing routes are involved for new generation alumina products, which are coming in big way. Most of these new grades of alumina are of smaller grain size. It has been found from the literatures that not too many studies on impact fatigue behavior of alumina with fine grain size (particularly sub-micron grain) have been done so far. So in the present work we have developed a machine, and using that we have seen the effect of grain size on impact fatigue behavior of alumina ceramics.

2 OBJECTIVES

The objectives of the present study are as follows.
i) To develop an Impact Testing Machine for carry out the Experiment
ii) To see the Effect of Grain Size on Impact Fatigue behavior
iii) To study the dynamic stress intensity factor of Alumina under impact loading,

3 EXPERIMENTAL METHODS

Sample preparation :Two grades of high purity commercially available alumina powders with (i) average particle

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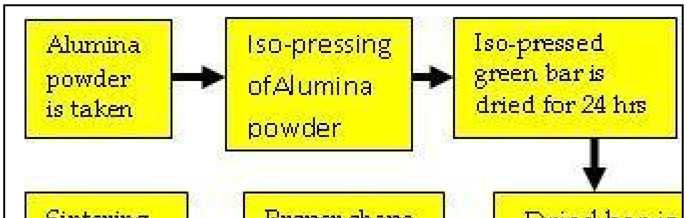
ISSN 2229-5518

size of 180 nm, purity 99.99 % and (ii) average particle size of > 0.4 μm, purity 99.8 % have been used for this study. The powders were used to obtain two different grained dense compacts with average grain size of 0.4μm (Fig 1) and 4 μm (Fig. 2). Alumina of different grain sizes was prepared from different powders using different methods as discussed below.

a. Samples were prepared in two different routes : (a) Isopressing followed by sintering and (b) slip casting followed by pre-sintering and sintering The process flow-sheets are given below.

The density of the sintered samples was measured using water-immersion method. The sintered and ground samples were then polished for measuring various mechanical properties like hardness, toughness etc. With the conventionally prepared (iso-pressed and sintered) samples, hardness was found to be 16.0 GPa (average) and toughness was 3.5-4 $Mpam^{1/2}$. The density was found to be around 99% of the theoretical value.
In case of alumina made with slip casting process, density was in excess of 98%, hardness was as high as 28 GPa and toughness was comparable with that of the other grain size.



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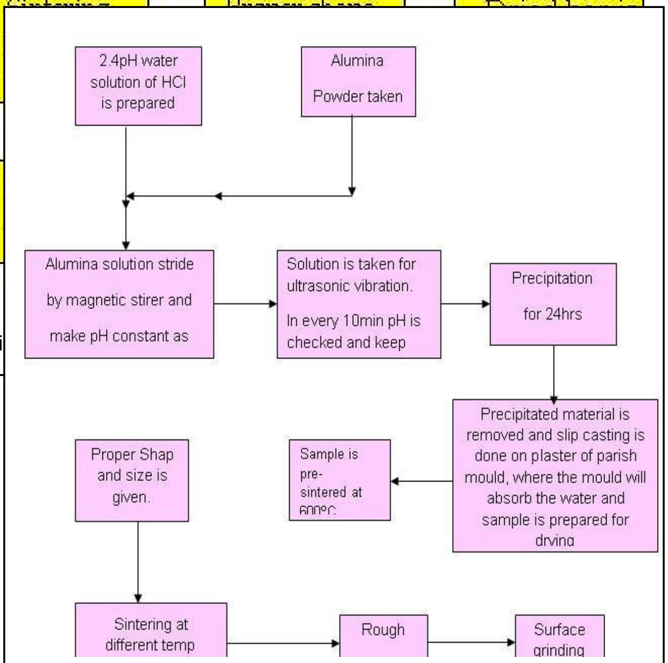
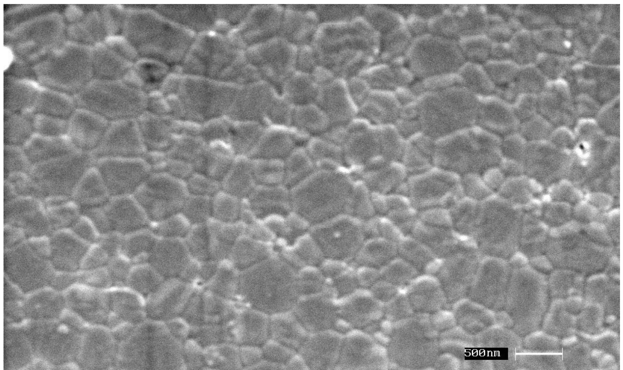


Fig. 2. Process flow sheet for slip cast alumina

Microstructure :

SEM photographs of the alumina samples of different grain sizes are shown below (Fig 3&,4).

Fig 3 Alumina samples sintered at 1275C following slip casting with a grain size of 0.4 μm



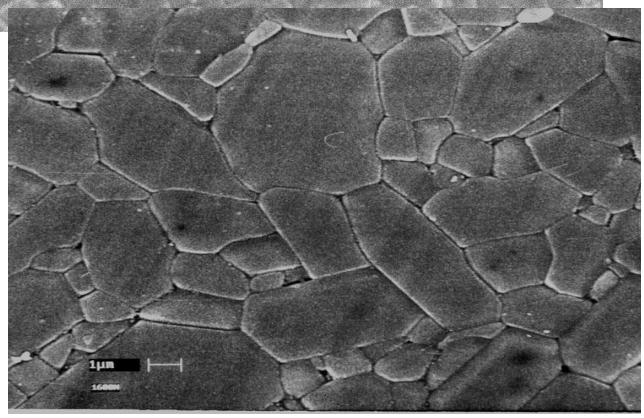


Fig 4 Alumina samples sintered at 1600C following iso-pressing and pre-sintering with grain size 4 micron

With alumina with smaller grain size the grains are mostly equiaxed where as for alumina with average grain size, grains are little bit elongated in shape which enhances grain bridging during crack propagation.A small set up for measuring the impact fatigue behave-our has been developed with a swinging pendulum of length of 54 cm and a wight in the form a spherical ball of diameters 36mm. The impact load is given to the test specimen perpendicular to its axis, which is rigidly fixed between two

ISSN 2229-5518

supports in a configuration resembling that of a Charpy test specimen. The bob (concentrated mass) is fixed at the end of the bar (swing arm), which is supported at almost frictionless hinge. The hinge is fixed inside the bearing, which is mounted in the bracket plate. The angular movement is given to the set (drum & bob) by the cam mounted on the low speed motor shaft. On the tensile surfaces of the beam specimens made of two different grained alumina, notches were created with different dimensions as mentioned below.

Fig 5 Experimental setup for impact fatigue testing

Dynamic stress intensity factors were found out using straight cracks on the tensile surfaces. Depths of the straight cracks were varied. Depth of notch is given by “a” and width of the specimen is given by “w”. “a/w” is the non dimensional crack depth. This was done for both the batch of alumina samples. It was not possible to produce exactly similar notches but it was ensured that the depths were comparable.

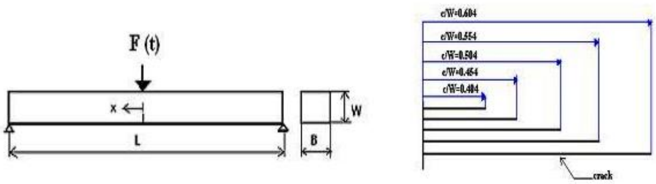


Fig 6 (a) Three point bend specimen with straight crack, (b) The range of crack depths in three point bend configuration.

4. Results & Discussion

To perform the test we have taken samples of different grain size such as 0.45μm and 4μm and it was observed that the fatigue of ceramic samples of smaller grain size was poorer than the higher grain size alumina. From the experimental results it was observed that with the increase of crack length the no of strike required for breaking the sample was decreasing for both the batch of samples. But it was observed that even if the crack dimension was more the no of strike required for breaking the sample of grain size 4μm was more than the sample of grain size of 0.45μm. This was probably due to the shape of the grains in higher grained samples which enhanced the scope of grain bridging. In case of number of impacts required for breaking, there was variation in the pattern as well.

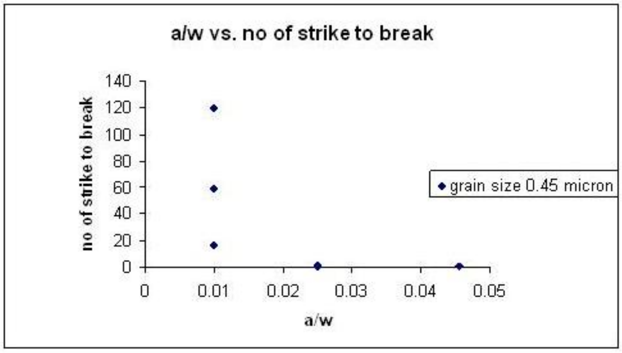
Table 1: Number of strikes reqd to break vs. a/w for alumina with grain size of 0.45 micron

EFFECTIVE LENGTH OF THE SAMPLE: 50mm TESTING WITH SMALL BALL & SMALL CAM a=Notch depth, w=Sample width					
GRAIN SIZE	NOTCH DEPTH	NO OF STRIKE	C/S OF THE SAMPLE	a/w	AVG. STRIKE
0.45μm	0.228mm	1	5x5 sq. mm	0.0456	1
0.45μm	0.228mm	1	5x5 sq. mm.	0.0456	
0.45μm	0.228mm	1	5x5sq. mm.	0.0456	
0.45μm	0.125mm	2	5x5sq. mm.	0.025	2
0.45μm	0.125mm	2	5x5sq. mm.	0.025	
0.45μm	0.125mm	1	5x5sq. mm.	0.025	
0.45μm	0.05mm	17	5x5sq. mm.	0.01	65
0.45μm	0.05mm	59	5x5 sq. mm.	0.01	
0.45μm	0.05mm	119	5x5 sq. mm.	0.01	

Fig. 7. Variation of number of strike to break with non-dimensional crack length.

From Fig. 7 it is evident that with alumina having lower grain size, samples got broken with almost a single blow in case of higher a/w (>0.025) while for the lowest a/w (=0.01), there was a large scatter in the data. It shows that with decrease in non-dimensional crack length (a/w), influence of other intrinsic material features (e.g. presence of other micro-structural discontinuities) got pronounced resulting in high scatter from around 20 to 120. It was also observed that a second degree polynomial equation nicely fits the data with high (>95% fitting) percentage fitting.

Table 2. No of strikes to required to break vs a/w for alumina with grain size of 4 micron.



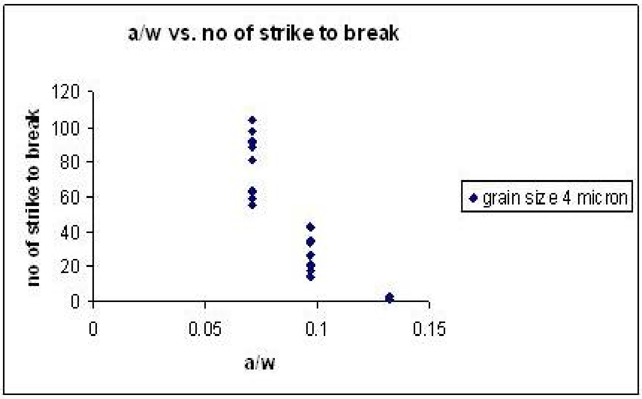


Fig. 8. Variation of number of strike to break with non-dimensional crack length

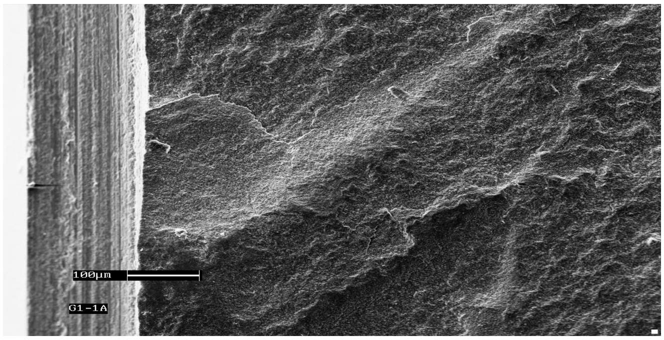


Fig 9 Cracks propagating (sideways) from the existing notch

EFFECTIVE LENGTH OF THE SAMPLE: 50mm TESTING WITH SMALL BALL& SMALL CAM a=Notch depth, w=Sample width					
GRAIN SIZE	NOTCH DEPTH	NO OF STRIKE	C/S OF THE SAMPLE	a/w	AVG. STRIKE
4µm	.662mm	2	5x5	0.1324	2
4µm	.662mm	2	5x5	0.1324	
4µm	.662mm	3	5x5	0.1324	
4µm	.662mm	2	5x5	0.1324	
4µm	.662mm	2	5x5	0.1324	
4µm	.662mm	2	5x5	0.1324	
4µm	.662mm	2	5x5	0.1324	
4µm	.485mm	15	5x5	0.097	28
4µm	.485mm	18	5x5	0.097	
4µm	.485mm	27	5x5	0.097	
4µm	.485mm	34	5x5	0.097	
4µm	.485mm	35	5x5	0.097	
4µm	.485mm	21	5x5	0.097	
4µm	.485mm	43	5x5	0.097	
4µm	0.356	55	5x5	0.0712	80
4µm	0.356	63	5x5	0.0712	
4µm	0.356	81	5x5	0.0712	
4µm	0.356	59	5x5	0.0712	
4µm	0.356	92	5x5	0.0712	
4µm	0.356	104	5x5	0.0712	
4µm	0.356	88	5x5	0.0712	
4µm	0.356	97	5x5	0.0712	

For the samples with higher grain size, scatter was comparatively low, even the samples with a/w as high as 0.07 (even bigger than the largest a/w in the previous case) could withstand around 80 impacts (average) before fracture. With another set of specimens having a/w 0.097 (almost double the value of maximum a/w in the previous case), average number of impacts sustained before fracture was around 30. Only one set having high a/w (almost three times the maximum a/w of the previous case) got broken with single impact.

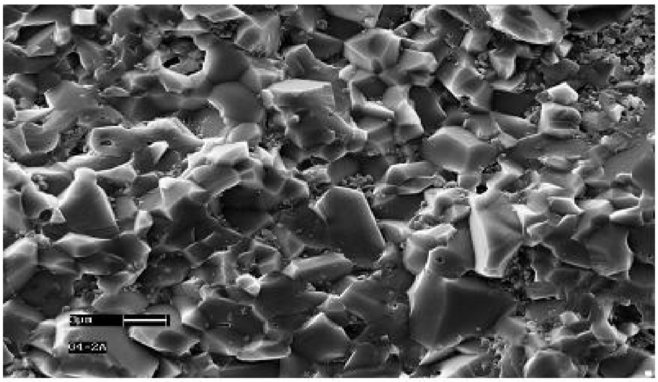


Fig. 10 Mixed mode of fracture in higher grained sample

From the SEM micrograph (Fig. 9), it is clear that the cracks started propagating from the sides of the notches and it followed a tortuous path. The crack apparently followed a new plane after a reaching a particular point or obstacle as observed on the fractured surface. In few other cases, there was apparently a crack initiation site (just at the tip of the notch) surrounded by semi-circular arc-shaped zone. Fig. 10 shows that there was a mixed mode of crack propagation: both trans-granular and inter-granular. From the data available so far, it is evident that higher grained alumina samples showed superior impact fatigue behaviour. The exact reason behind is not yet very clearly understood however a simple analysis of the two microstructures reveal that in case of higher grain size the shape was a little bit elongated in contrast with nearly equiaxed shape observed with sub-micron grained alumina. This caused grain bridging retarding partially the propagation of cracks along grain boundary in case of larger grained alumina. Furthermore with higher grain-size chance of crack-branching could be more that could reduce the energy available for the propagation of the main crack front.

5. Conclusions:

From the study it is evident that alumina with higher grain size showed superior impact fatigue behaviour in comparison with that of sub-micron grained alumina. Even with higher non-dimensional crack length (a/w), alumina specimens with bigger average grain-size withstood higher number of impacts prior to fracture. The superior impact fatigue behaviour was due to higher resistance to fatigue crack growth owing to grain bridging.

Acknowledgments

We acknowledge sincere help to the staff members of-Mechnical Engg Dept. & SBSE, Jadavpur University, Kolkata. One of the authors (M.K. Barai) sincerely acknwledge constant support from the HOD, Director and Principal of Future Institute of Engg and Management.

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