한국해양공학회 2003년도 추계학술대회 논문집 PP.35~40

Impact Damage in Ceramic Coated Glass according to Powder Size and Porosity Difference

Chang-Min Suh

Department of Mechanical Engineering, Kyungpook National University, 702-701, Korea

Ho-Dong Choi, Hyun-Yong Jung,
Sang-Chun Kim and Kyo-Suck Bai

Graduate School of Mechanical Engineering, Kyungpook National University, 702-701, Korea

KEY WORDS: Impact Damage, Ceramic Coating, Cone Crack, Radial Crack, Lateral Crack, Porosity

요 약:

본 연구에서는 취성재료이면서, 세라믹과 유사한 성질을 가지며, 내부균열관찰이 용이한 상업용 유리의 표면에 세라믹 플라즈마 용사 코팅한 후 입자 충격시험을 실시하였다. 코팅분말로는 내마모성 및 내충격성이 우수하여 산업계에서 널리 사용되고 있는 Al_2O_3 분말을 사용하였으며, 충격입자로는 고경도의 STB2 볼베어링강을 사용하였다. 공기압축기를 장착한 입자 충격시험기를 이용하여 강구입자 충격시험을 실시한후, 실체현미경을 이용하여 손상정도를 분석하였다. 그리고, 코팅입자의 크기 및 기공율에 따른 손상 정도를 분석 방법에 따라 손상정도를 비교 · 검토하였다.

1. Introduction

Recently, the application of ceramic materials has expanded because of the temperature limitations of metallic materials; Some machines are operated in high temperature environment and the operating temperature would increase continuously. So, the ceramic material is considered as new material for the machinery used in high temperature.

Especially, the development of CGT(Ceramic Gas Turbine) which can be used at high temperature was reported in a few nations to increase the performance. But, ceramic material is brittle and fragile for the impact and the fracture toughness of ceramics is lower than that of metal. So, when CGT of airplane rotates with high velocity, the FOD(Foreign Object Damage) must be considered, which is the impact damage by exterior particle from outside of ceramic turbine(Nakahira et al, 1990).

However, when small particles with high hardness and strength, such as bullets, sands, and pebbles, collide with a ceramic structure at a high velocity, serious damage and failure occur as a result of the impact(Mencik, 1992).

Accordingly, this study presents a ceramic coating technique for ceramic structures that reduce damage for the ceramic components by particle impact. The damage-reduction effect was tested for coated and uncoated materials subjected to particle impact. Soda-lime glass, which is similar to fracture behavior of structural ceramics, was used as the impact specimen, because its transparent interior makes investigation possible.

A steel ball(STB2) was used as the impact particle for impact test of uncoated smooth specimen. The same experiment was also performed on glass specimen coated with Al_2O_3 ceramic powders.

2. Experimental procedure

Fig 1 shows a schematic illustration of the impact-test equipment. The steel ball, contained in the center of the carrier, was fired from the carrier by the force of the compressed air. The air pressure was adjusted using an accumulator and a regulator. The compressed air was injected by opening a solenoid valve.

At the moment of injection, the carrier was discharged through an acryl barrel and arrested at the end of the barrel by a stopper. The steel ball then collided with the specimen at high velocity, as a result of inertia. The velocity was measured using two optical sensors and an oscilloscope.

This study was performed to investigate influence of powder size and porosity difference for six kinds of Al_2O_3 plasma coated glass specimen. The size of glass specimen was 40×40×5(mm).

In order to change porosity area and porosity percentage for each specimen, the powder size was changed as 30μm, 45μm, 60μm and the target distance was varied as 70mm and 120mm. SEM(Scanning Electron Microscopy) observation was conducted and measured porosities at SEM photos which was sketched on PC monitor by a mouse and on OHP film by hand. And they were analyzed by scion image s/w and planimeter respectively.

At the impact test, the lengths of radial crack and cone crack were analyzed and measured by using a stereo-microscope.

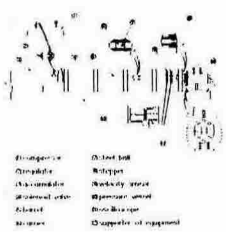


Fig. 1 Schematic illustration of experimental equipment of the particle impact test[3]

3. Result and discussion

(1) Analysis with the size of pore and porosity

The experiment clarified that the effect of the coated layer to the impact of steel ball particle was results of the pore.

Table 1 shows the coating condition of specimen. The general condition in the field is 70mm of spraying distance with 30μm powder size in the various ceramic plasma spraying conditions.

And Tables 2 and 3 show sand blasting and plasma coating. In usual, sand blasting is needed to make roughness in order to increase the coherent force between coating layer and glass specimen in thermal spraying method. And Al_2O_3 was used for sand blasting and coating powder. Actually, Al_2O_3 is very useful in industrial field for wear resistance and impact resistance in mechanical components.

Table 1 Mechanical properties of specimen and impact particle

Material		Young's modulus (GPa)	Hardness (Hv)	Specific Gravity	Ultimate Strength (MPa)
Specimen	Glass	[redacted]	560	2.6	50
Particie	Steel	[redacted]	880	7.83	1700

Table 2 Conditions of sand blasting

Particle	Particle size	Target distance
Al_2O_3	≤250μm	100mm

Impact angle	Blasting pressure
90°	4×10^2 MPa

Table 3 Conditions of plasma spraying

Coating powder	Current
Al_2O_3	650A
Powder size	Target distance
30, 45, 60μm	70, 120mm
Flow quantity (Ar)	Flow quantity (H_2)
60ℓ/min	12ℓ/min
Feed quantity(Al_2O_3)	Feed quantity (Ar)
25g/min	10ℓ/min

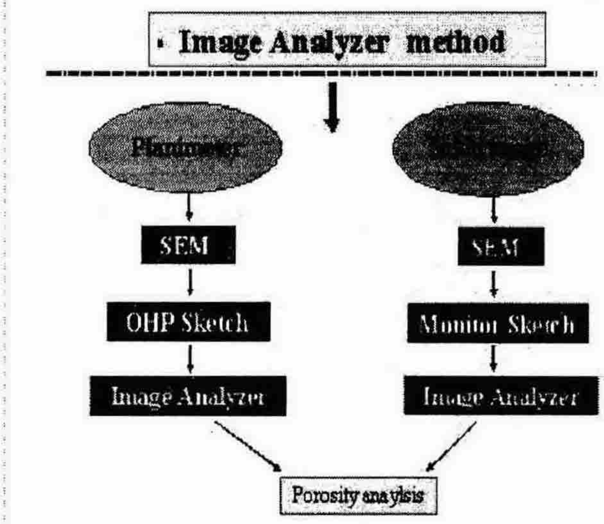


Fig 2. Procedure image analyzer method

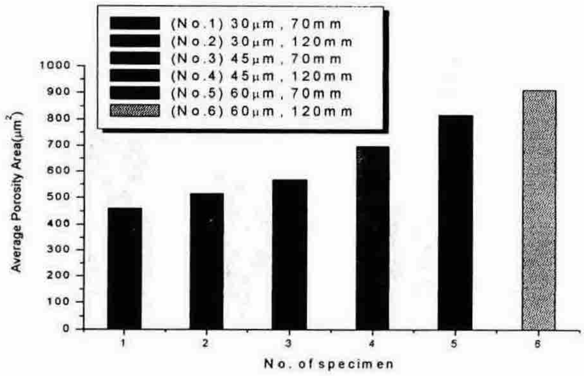


Fig. 3 (a) Histograms of porosity area by planimeter

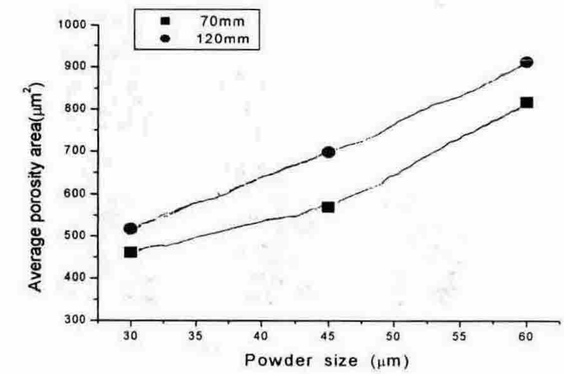


Fig. 3 (b) Comparison of average porosity area between powder size and distance of plasma coating

Fig.2 shows the process of in the image analyzer method. The spraying distance affects on the size of pore and porosity. It is possible to forecast the property of the ceramic plasma coating by measuring the porosity of sprayed layer. That's the need of the accurate measurement of pore size and porosity of sprayed layer.

There are several methods to measure the density of sprayed layer; generally preferred MIP(Mercury Intrusion Porosimetry) etc. The MIP, measuring porosity with the quantity of mercury penetrated into the pore, has the weak point of the probability of damage to the sprayed layer.

Image analyzer method was adopted to measure the size or pore and porosity with a limited three dimensional application.

Fig 3. shows histograms of average porosity area by planimeter, micro structure of sprayed layer of the isotropic specimen cut in quarter was vertically observed by SEM as shown in Fig.4. The size of pore and porosity was measured by the image analyzer(Scion Image s/w and planimeter) with the polished spray film. In the Fig.3, the porosity and area of pore in No.6 are the biggest value among 6 cases. The damage level was also minimized in No.1, and was maximized in No.6 shown as in the Fig.3.

And it also shows that the closer spaying distance decreases the damage level compared with the same depth of sprayed layer.

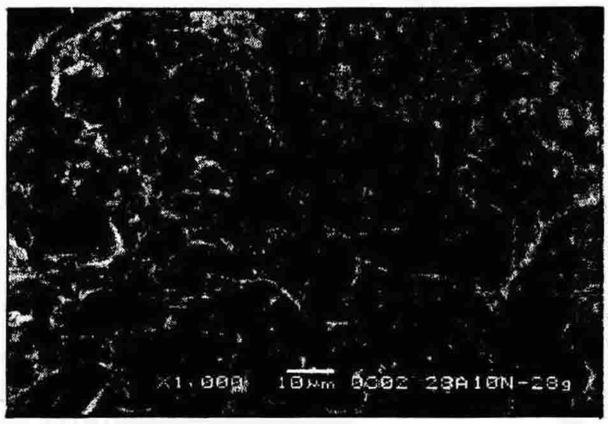
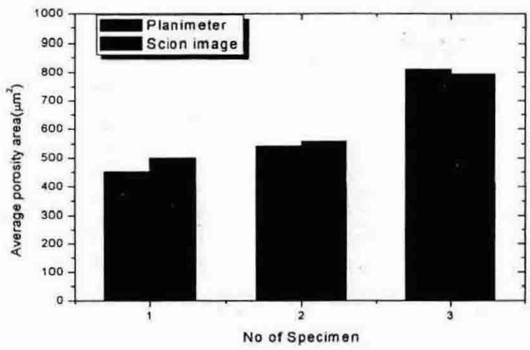
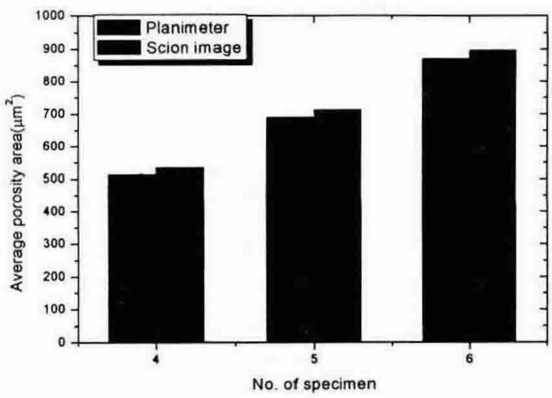


Fig 4. SEM fractography on the cross section (No.1 Powder size 30μm , target distance 70mm and sketch of porosity at OHP film)



(a)



(b)

Fig.5 Comparison of porosity percentage by planimeter and image analyzer

(a) Specimens of No.1, No.2, and No.3

(b) Specimens of No.4, No.5, and No.6

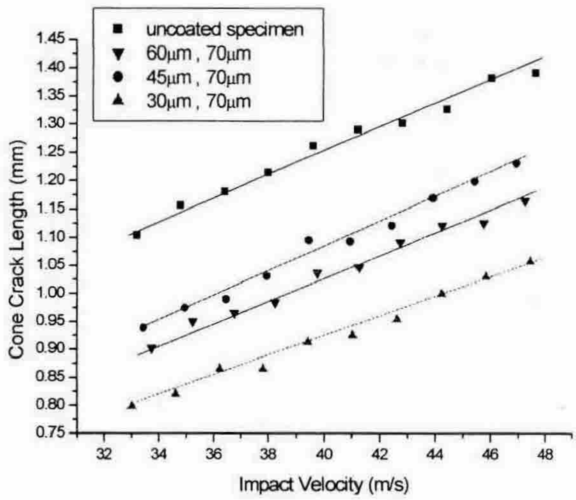
Fig.5 shows a comparison of average porosity percentage by planimeter and image analyzer for each specimen. As represented in Fig.5, there wasn't significant differences between two kinds of method according to measuring method.

(2) The variation of crack length

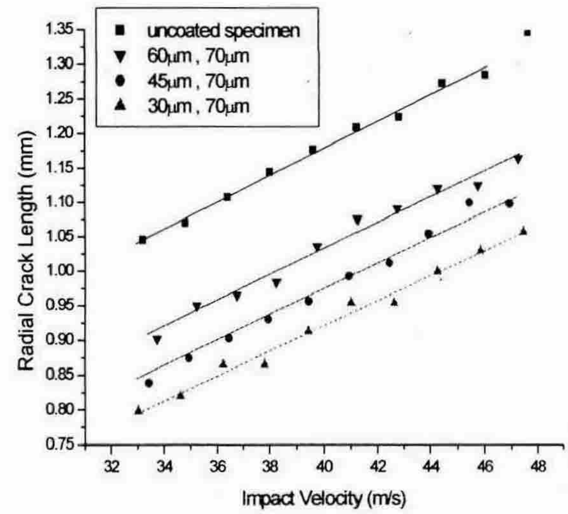
As a result of the steel ball impact test. various types of crack occurred in the specimen; ring crack, cone crack, and lateral crack according to the variation of impact load and stress distribution.

Especially radial crack, vertical with the surface, is emerged with the lateral crack developed to the surface from the margin of cone crack, damage the surface of material by delamination of the surface particle with the crushing.

Ring cracks were initiated at a low impact velocity and only resulted in a minor surface damage with no effect on surface delamination or decrease in strength. In high impact velocity, it is difficult to find ring crack because of crushing and delamination.



(a)



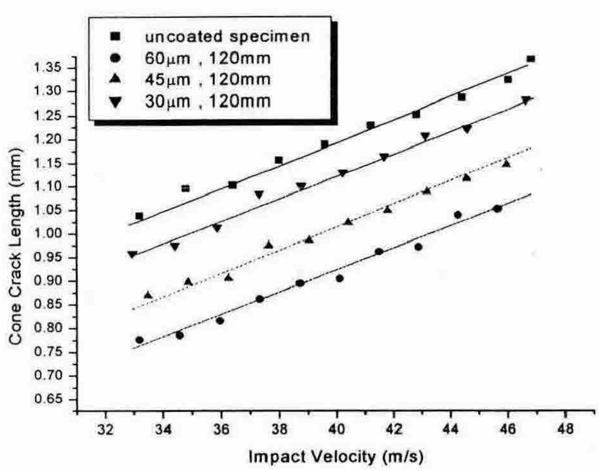
(b)

Fig.6 Variation of cone crack length according to impact velocity and coating conditions under 3 bar.

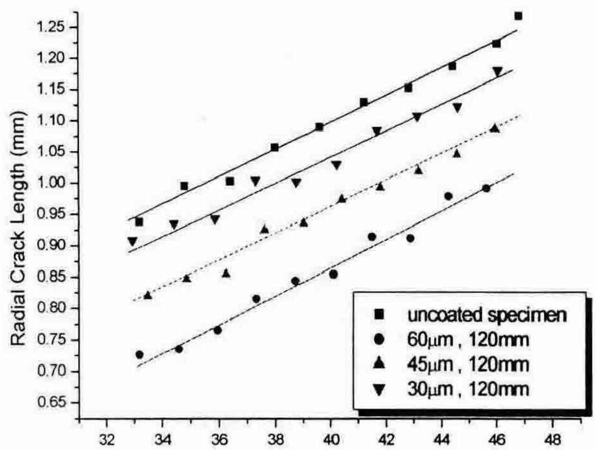
The radial crack is plenty and the longest one from the central impact point to the marginal part of the basic material. It scrutinized the length of the crack varied by the stress level of specimen with each impact speed.

In particular, a radial crack that incorporates with a lateral crack produces delamination and serious surface erosion. Accordingly, a coating will prevent deformation of size and deformation due to surface particle delamination, which controls the function of it.

The mechanism of radial crack growth is reported by Johnson(Johnson, 1968). When a steel ball impact on a specimen surface, a radial crack is initiated to radial direction by large tensile stress around elastic-plastic border of contact area. After steel ball impacting, it is reported that the radial crack grow to the radial direction by residual plastic strain which causes a spring back of unloading process in specimen(Knigh *et al.*, 1977).

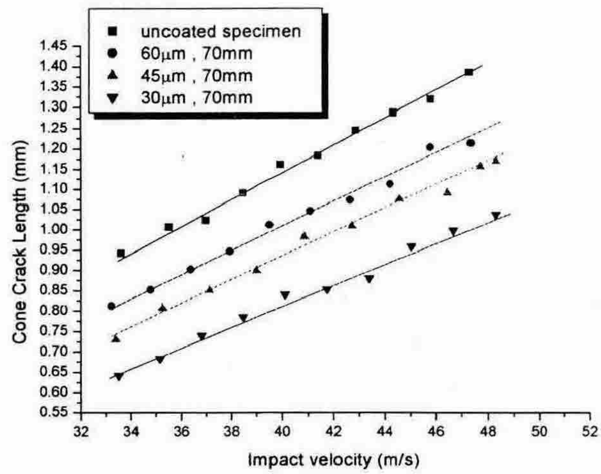


(a)

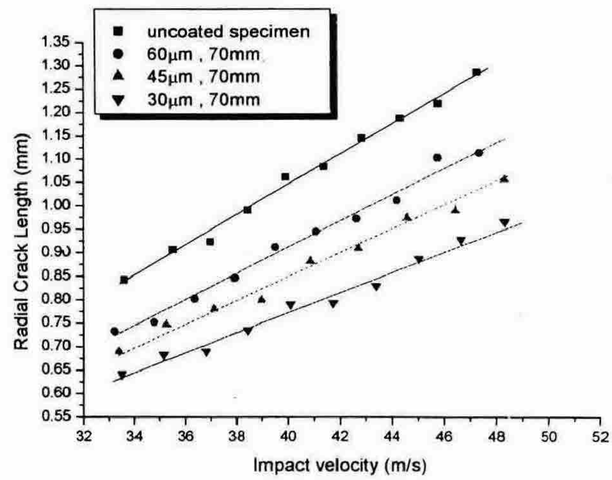


(b)

Fig.7 Variation of cone crack and radial crack length according to impact velocity and coating conditions under atmosphere.



(a)



(b)

Fig.8 Variation of cone crack and radial crack length according to impact velocity and coating conditions under 460 torr.

Figs. 6, 7, and 8 show the variation of the cone crack and radial crack at the different stresses to the glass specimen, The length of radial crack with the tensile stress on the surface is much bigger than the case of without the tensile stress, and it decreases with the compressive stress. Damage reduction effect is due to the high number of pores distributed in the coating layer that absorb the impact load and reduction of contact radius.

In addition, the high hardness coating layer also supposedly acts an important factor in the damage reduction.

Radial crack was observed from the impact of the steel ball with radial shape simultaneously with cone crack. As well it was reported that radial crack was occurred by intensive cylindrical tensile stress from the boundary of the contact surface with the basic material, and it was developed much with radial shape by the change of cylindrical stress of the boundary into tensile stress created by residual plasticity strain of internal basic material with the spring back effect in the unloading process after the original impact(Chaudhri *et al.*, 1986)

The developed radial crack, vertically with the surface, is emerged with the lateral crack developed to the surface from the margin of cone crack, which damages the surface of material by delamination of the surface particle with the crushing.

In addition, the experimental results showed porosity size and porosity percentage depended on powder size and target distance. As well the specimen of the case at powder size 30㎛, and target distance 70㎜ is the best condition among others (powder size 45, 60㎛, target distance 120㎜).

4. Conclusions

In the consequence of this study, the compressive stress decreased the length of cone crack & radial crack, but on the other hand the tensile stress increased the length of cone crack and radial crack.

In the other words, brittle specimen, ceramic for example, get less damage from an impact with short cone crack and radial crack. Sharply contrasted with former case, brittle specimens get much damage at tensile stress.

Acknowledgement

This study was supported by Brain Korea 21 Project.

Reference

Mencik, J., Strength and Fracture of Glass and Ceramics, ELSEVIER SCIENCE PUBLISHING Co., Inc., 1992, Glass Science and Technology, Vol. 12.

Nakahira, H., Nagai, J., and Takeuchi, J., Physical properties of some oxide coatings by low pressure plasma spraying, Plasma Technik Sympoium, 2nd ed., 1990, Vol. 2, pp.141-151.

Knight C.G., Swain M.V., Chaudhri M.M., Impact of Small Steel Spheres on Glass Surfaces , *J. Mater. Sci.*, 1977, Vo. 12, pp. 1573-1586.

Chaudhri M.M., Kurkjian C.R., Impact of Small Steel Sphere on the Surfaces of Normal and Anomalous Glasses , *J. Am. Ceram. Soc.*, 1986, Vol. 69(5), pp. 404-504.

Wiederhorn S.M., Lawn B.R., Strength Degradation of Glass Resulting from Impact with Spheres , *J. Am. Ceram. Soc.*, 1977, Vol. 60(9-10), pp. 451-458.

Johnson, K. L., Engineering Plasticity, Cambridge Univ. Press, London, 1968.

Suh C.M., Jung S.M., Lee M.H., An Experimental Study on Damage Mechanism of Particle Impact in a Scratched Glass, *Journal of KSME*, 1996, Vol. 20(7), pp. 2196-2204.

Suh C.M., Kim S.H. and Kim D.K, Finite Element Analysis and Experimental Study about Damage Behavior of Glass by Oblique Impact of Steel Ball, *Journal of KSME*, 2001, Vol. 25(5), pp. 899-905.

Chaudhri M.M, Walley S.M., Damage to Glass Surfaces by the Impact of Small Glass and Steel Ball, *Philosophical Magazine A*, 1978, Vol. 37, No. 2, pp. 153-165.

Suh, C.M., Lee, M.H., Hwang, B.W., and Kim, S.H., Damage Behavior in Ceramic Plasma-Coated and Uncoated Glass with Steel Ball Impact, Journal of American Ceramic Society, 2003, Vol.86, No.7, pp.1220-1222.

2003년 9월 30일 원고 접수
2003년 월 일 최종 수정본 채택