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SHAPE FACTOR ANALYSIS OF ABRASIVE PARTICLES USED IN SLURRY ABRASION TESTING

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Abstract - The engineering components are subjected to surface damage by slurry abrasion such as transportation pipes carrying ore and mineral slurries, extruders, sand pumps and agitators, Apart from stress, abrasive particle hardness, slurry concentration, particle size and shape significantly influences slurry abrasion rate. The effect of abrasive particle shape on slurry abrasion behaviour of steels and cast irons which are widely used for wear protection has not been studied. The particle shape assumes significant importance due to fracture and fragmentation of the particles during the process of abrasion. In the present work, the particle shape characterization of silica sand abrasive particles was carried by shape factor analysis using image analysis technique. An attempt was made to correlate the different measures of shape factor with particle size of abrasive particles over a wide range. The characterization of slurry abrasion tester was carried out using slurry abrasion tester with silica sand slurry. The effect of sliding distance on slurry abrasion volume of mild steel was studied. The volume loss increased linearly with sliding distance. The scanning electron microscopic observations of worn our surfaces showed micro-ploughing and cutting as mechanism of material removal.

Keywords *- slurry, abrasive, shape, shape factor, angularity, image analysis.*

I. INTRODUCTION

The wear by abrasion accounts for more than 50 % failures of engineering components. In abrasive wear the material is removed from the surface by abrasives which are either fixed to the surface or flow over the surface. Apart from stress, velocity, the properties of abrasive particles significantly influence abrasion rate. With increase in hardness of abrasive particle, the abrasion increases although not proportionately. In fact the relative hardness of abrasive particles decides soft or hard abrasion reflecting in either mild or severe abrasion [1-3].

The effect of particle size on abrasive and erosive wear is well established and well documented in the literature [4-9]. However the effect of particle shape has not been studied by many researchers. The particle shape significantly affect abrasion rate, spherical particles causing less wear than angular particles. In practice, the abrasive particles exhibits different shapes due to complex processes involved during crushing and grinding. The shape of the abrasive particle influences the contact load and transition to elastic to plastic contact. The morphology of worn surfaces depends on the shape of abrasive particles. The rounded particles generate crates and smooth grooves while angular particles produced sharp indents and narrow cutting grooves resulting in relatively higher wear rates [9-11].

The abrasion rate is also significantly affected by abrasivity of particles, which in turn depends on orientation of abrasive particles with respect to wearing surface. The abrasive particle shape also becomes important due to occurrence of particle fracture and fragmentation during the process of wear. The fractured particles with angular morphology can cause further damage to the surface [11-12]. In this context, the characterization of particle shape becomes important.

There are three commonly used shape factors – circularity, and Aspect ratio and elongation. One measure of shape is to quantify the 'closeness' to a perfect circle. The circularity is expressed as $4\pi A/P^2$, where A is the particle area and P is its perimeter. Circularity is a ratio of the perimeter of a circle with the same area as the particle divided by the perimeter of the actual particle image. There are alternative definitions of circularity but the definition shown above has a squared term in the numerator and denominator in order to sensitize the parameter to even the most subtle variations in the area-perimeter relationship. Circularity is a good measure of what, in human terms, we could describe as "deviation from a perfect circle. The other measure of shape factor is Elongation. A shape symmetrical in all axes such as a circle or square will have an elongation value of zero whereas shapes with large aspect ratios will have an elongation closer to 1. The illustration of circularity and angularity is shown in Fig 1 and 2. A smooth ellipse has a similar elongation as a spiky ellipse of similar aspect ratio. The image analysis provides two other important benefits; number-based resolution and recording of images. It provides the user with additional information which contributes to a deeper understanding of the product or manufacturing process. The most common measures of particle shape are the shape factors; the form factor, roundness, elongation and aspect ratio. The shape factors describe the tendency of a particle to deviate from an ideal geometrical prototype often a sphere. This reasoning promotes the impression that shape factors are suitable measures of abrasive potential. It has been demonstrated that there is no simple relationship between the magnitude of shape factors and wear rate. There have been limited studies carried out to characterize abrasive particle shape [13-17] and fracture and fragmentation of abrasive particles with respect to slurry abrasion of steels and cast irons, which are widely used for wear protection of engineering components. [18-22].

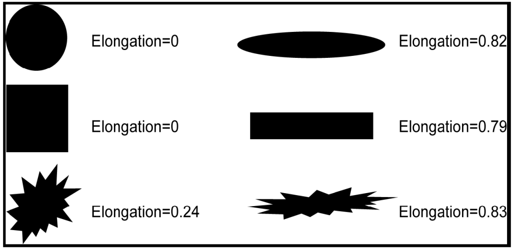


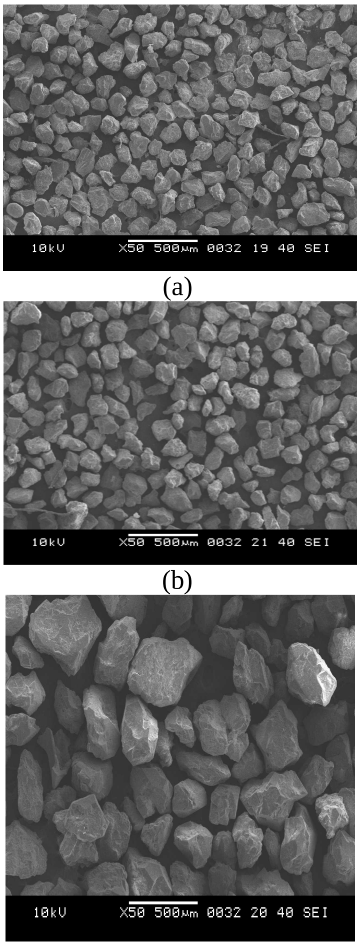
Fig.1 : Illustration of circularity

Fig. 2 : Illustration of angularity and elongation

In the present study the shape factor analysis of silica sand particles as a function of their size is presented. The silica sand has harder than those abrasive particles encountered in conveyor belts, transportation of ore and mineral slurries through pipelines, sand pumps, extruders and agitators where surface damage by slurry abrasion is a potential problem. The abrasive particles were crushed, ground and subjected to sieve analysis. The representative samples were observed under scanning electron microscope to study size distribution and shape. The shape factor analysis was carried out using Image analysis. An attempt is made to correlate different measures of shape factor with particle size. The slurry abrasion tester to be used for slurry abrasion testing using abrasive these slurries was also characterized.

II. EXPERIMENTAL

The silica sand particles were selected in the present investigation as the slurry medium. The silica sand particles were sieve analyzed to obtain different fractions and representative samples were coated with gold for observing particle size distribution and shape. Six different particle size distributions were used for particle shape factor analysis which were 600-850 µm, 450-600 µm, 300-450 µm, 212-300 µm, 150-212 µm and 106-150 µm. Fig 3 shows SEM photographs of some of the silica sand particles used in this investigation. The shape factor measurements were carried out by the technique reported earlier. For shape factor analysis the particles were spread on glued to the glass slide and observed under optical microscope. Twenty different particles were selected and the relevant dimensions were measured using image



(a)

(b)

(c)

Fig. 3 (a-c) : SEN photographs of silica sand particles (a) 106-150 µm (b) 212-300 µm (c) 300-450 µm

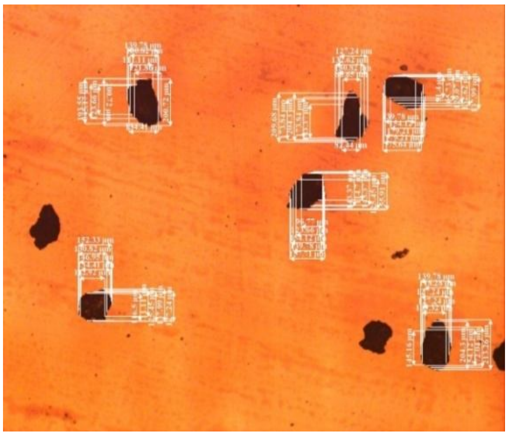


Fig. 4 (a) : Optical microscope image of silica sand particle (106-150 µm)

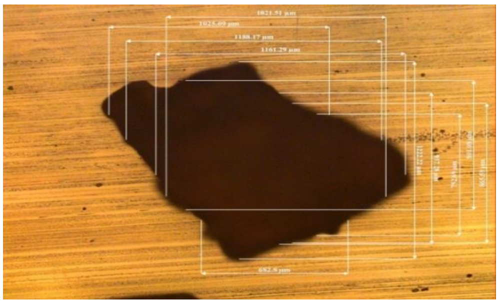


Fig.4 (b) : Optical microscope image of silica sand particle (300=450 µm)

Analysis software. A representative photograph of the particles analyzed is shown in Fig 4 (a&b). The mean values of five lines drawn on the particle projection for each axis were taken as the real length (L) and width (W) values of that particle [23]. Thus, the area (A) and perimeter (P) of the particle projection can be calculated on the basis of the measured length and width as given in equations (1-4);

Area $A = \pi L W / 4$ (1)

Perimeter, $P = \pi / 2 \, [3/2 \, (L+W) - (L/W)^{1/2}]$ (2)

Shape factor $SF = 4\pi A / P^2$ (3)

Relative width $= W / L$ (4)

The slurry abrasion test with 300-450 µm silica sand particles was performed on mild steel (0.19% carbon) using slurry abrasion tester as shown Fig 4. The slurry was prepared by mixing 1.5 kg of silica sand particles in 1 litre of distilled water and at a load of 125 N. The total number of wheel revolution was increased from 500, 1000, 1500 to 2000 thus increasing the sliding distance of slurry particles. The specimens for slurry abrasion testing were rectangular blocks measuring 57.2 mm (length) X 25.4 mm (width) x 9.42 mm (thickness).

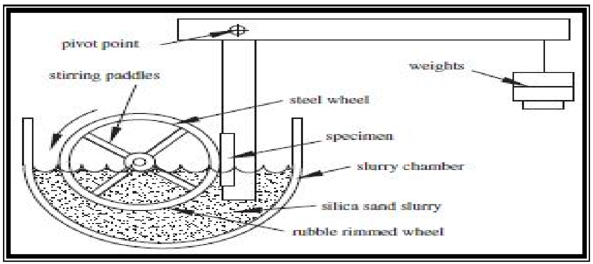


Fig. 5 : Schematic sketch of slurry abrasion test apparatus

The specimens for abrasion testing were polished with successive silicon carbide papers followed by polishing with alumina slurry and cleaned with ethyl alcohol and then weighed using a digital electronic balance to the accuracy of 0.1 mg. After the test, specimens were cleaned with dry compressed air followed by cleaning with ethyl alcohol and then weighed. The loss in mass (g) was calculated as the difference of initial and final weight. The mass loss was used to calculate the volume loss after slurry abrasion test. The worn out specimen was ultrasonically cleaned before observing morphology of the surface under scanning electron microscope.

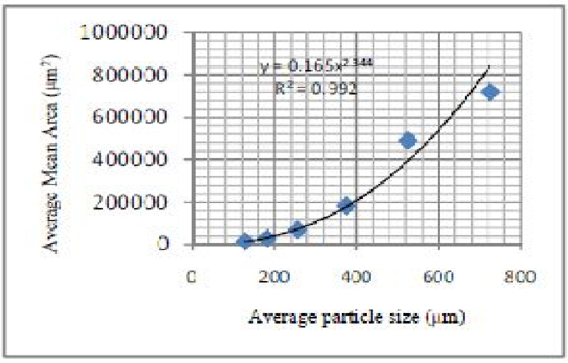
III. RESULTS & DISCSUSSION

The different measures of shape factors are plotted vs. average particle size of silica sand and are shown in Fig 6 (a-e). From Fig 6 (a) and (b) it can be observed that the mean area of the particles increased from 15134.39 μm^2 to 719619.9 μm^2 when the mean particles increased from 128 µm to 725 µm, whereas perimeter increased from 441.6184 µm to 3021.42 µm thus showing more than seven times increase. The data points in Fig 6 (a) were fitted by power law line indicating power law dependence of mean particle area on average particle size. The mean perimeter of the particles exhibited almost linear increase with average particle size as seen from Fig 6 (b). The other measures of particle shape; relative width , aspect ratio and shape factor as plotted in Fig 6 (c-e) exhibited different trends as compared to mean area and perimeter. The data points in Fig 6 (c-e) were fitted by polynomial equation of 2nd , 3rd and 4th order. The dependence of mean area, mean perimeter, average mean relative width, average mean aspect ratio and average mean shape factor on average particle size of silica sand particles is shown in Fig. 6 (a-e), respectively. The trends shown by different measures of particle shape analysis can be attributed to different particle size distribution from finer (106-150 µm) to coarser (600-850 µm). The particle size distribution for finer particles was relatively narrower and increased with increasing coarseness of the particles.

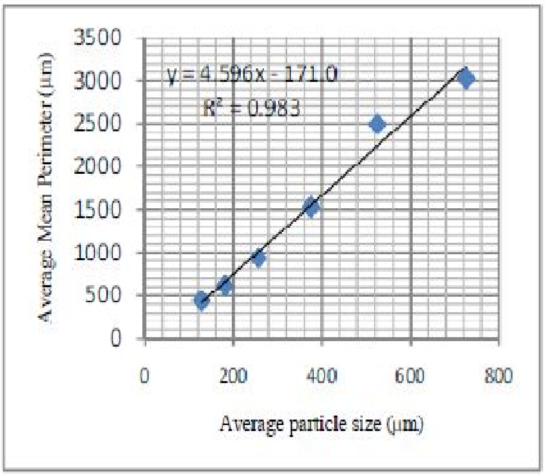
The effect of product of sliding distance and load on volume loss of mild steel is shown in Fig 7.The data points were fitted by straight line. It can be observed that slurry abrasion volume loss increased linearly with sliding distance and hence the product of S (sliding distance) x (Load). The dependence of slurry abrasion volume loss (V) can be expressed by the Archrad's equation [11],

$V = K. S \times L / H,$ (5)

Where H is the hardness of the mild steel surface. The visual observations of the abraded surface is shown in Fig 8 and SEM (scanning electron microscope) photograph the abraded mild steel surface after 2000 revolutions is shown in Fig 9.



(a)



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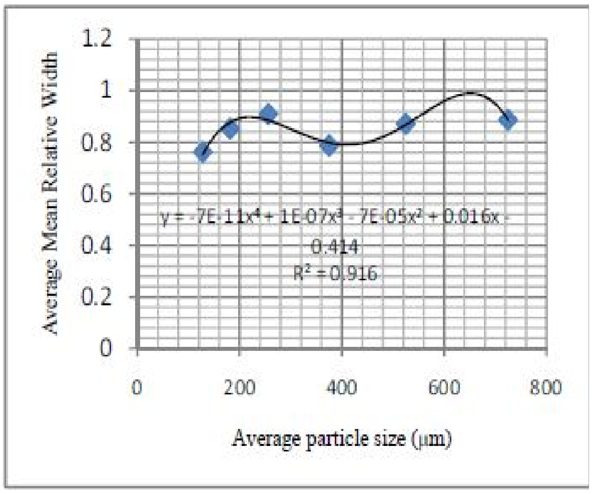
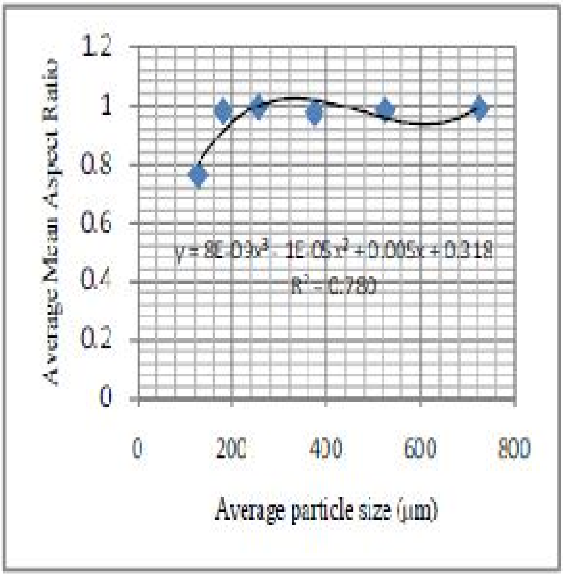
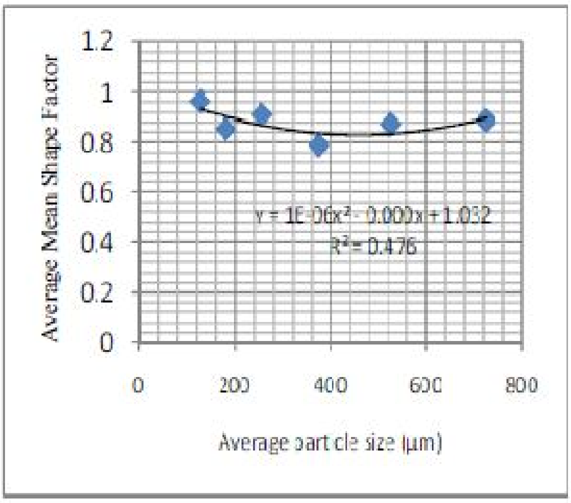


(c)

Fig. 6 (a-c) : Different measures of shape factor plotted vs average particle size (a) Average mean area (b) average mean parameter (c) average mean relative width



(d)



(e)

Fig. 6 (d-e) : Different measures of shape factor plotted vs average particle size (d) Average aspect ratio (e) average mean shape factor

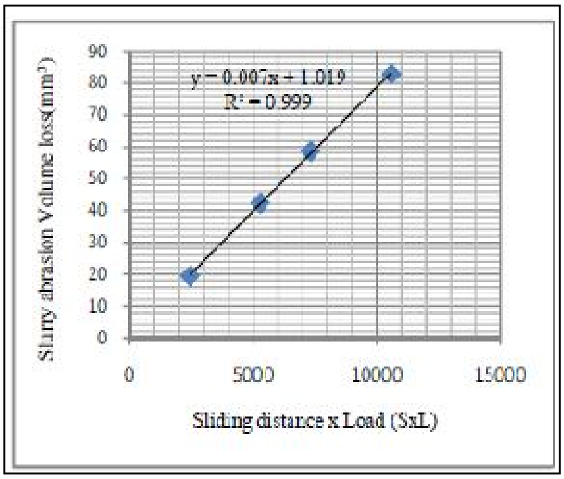


Fig. 7 : Slurry abrasion volume loss of mild steel vs. product of sliding distance (S) and Load (L) when abraded with silica sand particles at a load of 125 N.

The deep parallel groves caused by silica sand particles can be seen from photograph of the worn out surface as shown Fig 8(a). The SEM photograph (Fig 8b) shows severely abraded surface of mild steel, with width of grooves in the range of 10-20 µm. The ploughed material still attached to the groove can be seen at the top of the photograph. The material removed by micro-cutting [2-3,11] action of abrasive particles also can be seen at the top left portion of the photograph.

Fig. 8 (a) : Photograph of worn out surface of mild steel after slurry abrasion test with 300-450 µm silica sand particles at load of 125 N.

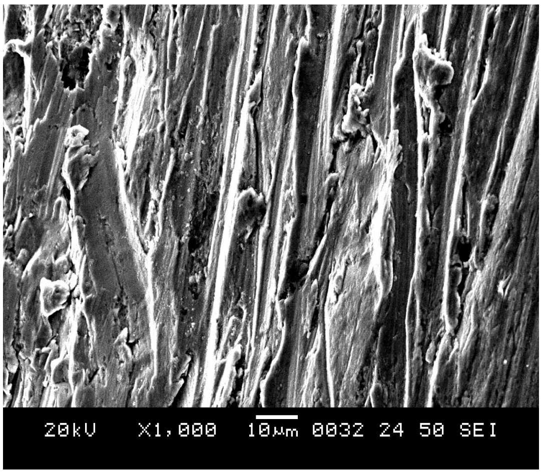


Fig. 8 (b) : Scanning electron micrograph of worn out surface of mild steel Photograph of worn out surface of mild steel after slurry abrasion test with 300-450 µm silica sand particles at load of 125 N.

IV. CONCLUSION

The shape factor analysis of silica sand particles over a wide range was performed using image analysis technique. The characterization of slurry abrasion test apparatus was carried out on mild steel with silica sand abrasive particles. The different trends were observed in correlating different measures of shape factor with average particle size of silica sand. The average mean area of particles exhibited power law dependence and average mean parameter of particles exhibited linear trend with average particle size of silica sand particles. The dependence of average mean relative width, average mean aspect ratio and average shape factor on particle size was expressed by polynomial equations. The slurry abrasion volume loss of mild steel increased linearly with sliding distance. The Scanning electron micrograph revealed micro ploughing and micro-cutting as mechanism of material removal; from the surface.

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REFERENCES

[1] Blau PJ, Friction, lubrication and wear technology. ASM Handbook, vol. 18, ASM International, The Materials Information Society, 1992

[2] S.G. Sapate , A.D. Chopde, P.M. Nimbalkar, D.K. Chandrakar, “ Effect of microstructure on slurry abrasion response of En-31 steel,” Mater and Des,vol, 29,pp.613-621,2008

[3] S. G. Sapate, J. Raut, “Investigations on Wear by Slurry Abrasion of Hardfaced Low Alloy Steel,” Proc. of II Int. Conf. on Advances in Mechanical Engineering, AMAE,Noida, 2011

[4] J.G. Chacon-Nava , A.Martinez-Villafan˜, F.Almeraya-Calderon , J.A. Cabral-Miramontesa, M.M.Stack, “Some remarks on particle size effects on the abrasion of a range of Fe based alloys,” Trib Int.,vol 43,pp. 1307–1317, 2010 fig

[5] I. Misra, Finnie, “On the size effect in abrasive and erosive wear,”Wear, vol. 65, pp.359-373,1981

[6] R. Gåhlin, S. Jacobson, “The particle size effect in abrasion studied by controlled abrasive surfaces,” Wear, vol. 224 ,pp.118-125,1999

[7] H.McI. Clark, R.B. Hartwich, “A re-examination of the ‘particle size

[8] effect’ in slurry erosion,” Wear , vol. 248, pp. 147–161,2001.

[9] J.Y. Shu, N.A. Fleck, “The prediction of a size effect in micro-indentation,” Int. J. Solids Struct. Vol. 35 (13), pp. 1363–1383.1998

[10] G.W. Stachowiak, “Particle angularity and its relationship to abrasive and erosive wear,” Wear, vol. 241,pp214-219,2000

[11] I.M. Hutchings, Tribology Friction and Wear of Engineering Materials, Edward Arnold; 1992

[12] G P.Tilly, “A two stage mechanism of ductile erosion,” Wear, 23, pp.vol.23, pp. 87–96, 1973

[13] D.V. De Pellegrin, G.W. Stachowiak, “A new technique for measuring particle angularity using cone fit analysis,” Wear, vol. 246, pp. 109-119, 2001

[14] W.J. Head, M.E. Harr, “The development of a model to predict the erosion of materials by natural contaminants,” Wear, vol. 15,pp.1-46,1970

[15] M.G. Hamblin, G.W. Stachowiak, “A multi-scale measure of particle abrasivity, and its relation to two-body abrasive wear,” Wear, vol. 190, pp. 190-196,1995

[16] D.V. De Pellegrin, G.W. Stachowiak, “Assessing the role of particle shape and scale in abrasion using ‘sharpness analysis’: Part 1. Technique development,’’ Wear, vol, 253, pp. 1016–1025,2002.

[17] D.V. De Pellegrin, G.W. Stachowiak, “Assessing the role of particle shape and scale in abrasion using ‘sharpness analysis’. Part II. Technique evaluation,” Wear, vol. 253, pp. 1026–1034 (2002) 1026–1034

[18] M.G. Hamblin, G.W. Stachowiak, “A multi-scale measure of particle abrasivity, and its relation to two-body abrasive wear,” Wear, vol. 190,pp.190-196,1995

[19] Raadnui S, “Wear particle analysis - Utilization of quantitative computer image analysis, a review,” Tribol Int, vol, 38, pp. 871–878, 2005

[20] N.B. Dube, I.M. Hutchings,“Influence of particle fracture in the high-stress and low-stress abrasive wear of steel,” Wear, vol.,233–235,pp. 246–256,1999.

[21] P Hosseini, P Radziszewski, “Combined study of wear and abrasive fragmentation using Steel Wheel,” Wear, vol, 27, pp. 689–696, 2011.

[22] J. Bridgwater, R. Utsumi1, Z. Zhang, T. Tuladhar, “Particle attrition due to shearing—the effects of stress, strain and particle shape,” Chem Engg Sci.,vol. 58, pp. 4649 – 4665 , 2003

[23] M Yekeler, “Breakage and Morphological Parameters determined by Laboratory Tests,” Handbook of Powder Technology, 2007

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