Chapter V

Results and Discussion

5.1 Effect of comminution conditions on the size distribution

Figure 5.1 shows the size distributions of product ground under various conditions whereas the relationship between average size and grinding time is shown in **figure 5.2** and the relationship between average size and weight ratio between media and feldspar is shown in **figure 5.3**,respectively. From these figures and previous knowledge, it can be concluded that as the grinding time or weight ratio between media and feldspar increases, the average size of ground product decreases. From **figure 5.1**,it is found that the size distribution for the case with grinding time of 20 minutes and weight ratio between media and feldspar of 4:1 is almost the same as that of the case with grinding time of 15 minutes and weight ratio between media and feldspar of 5:1. The average size and its deviation of the first case $\bar{x} = 191.66$ micron , $\sigma = 2.469$ while for the second case $\bar{x} = 171.06$ micron , $\sigma = 3.002$.

On the other hand, **figure 5.4** shows the comparison of flowability and particle shape of the ground product in sizes range 149-210 micron from two comminution conditions mentioned above. It can be seen that the flowability and particle shape of the ground product in **figure 5.4** is clearly different. However, it can be seen that the size distribution characteristics of the ground product obtained from the different comminution conditions shown a very small difference. From these results, it should be able to infer that only the size distribution characteristics of the ground particles is insufficient to discriminate the difference of particle's behavior especially, flow behavior, which involves with many important processes such as storaging, conveying and so on.

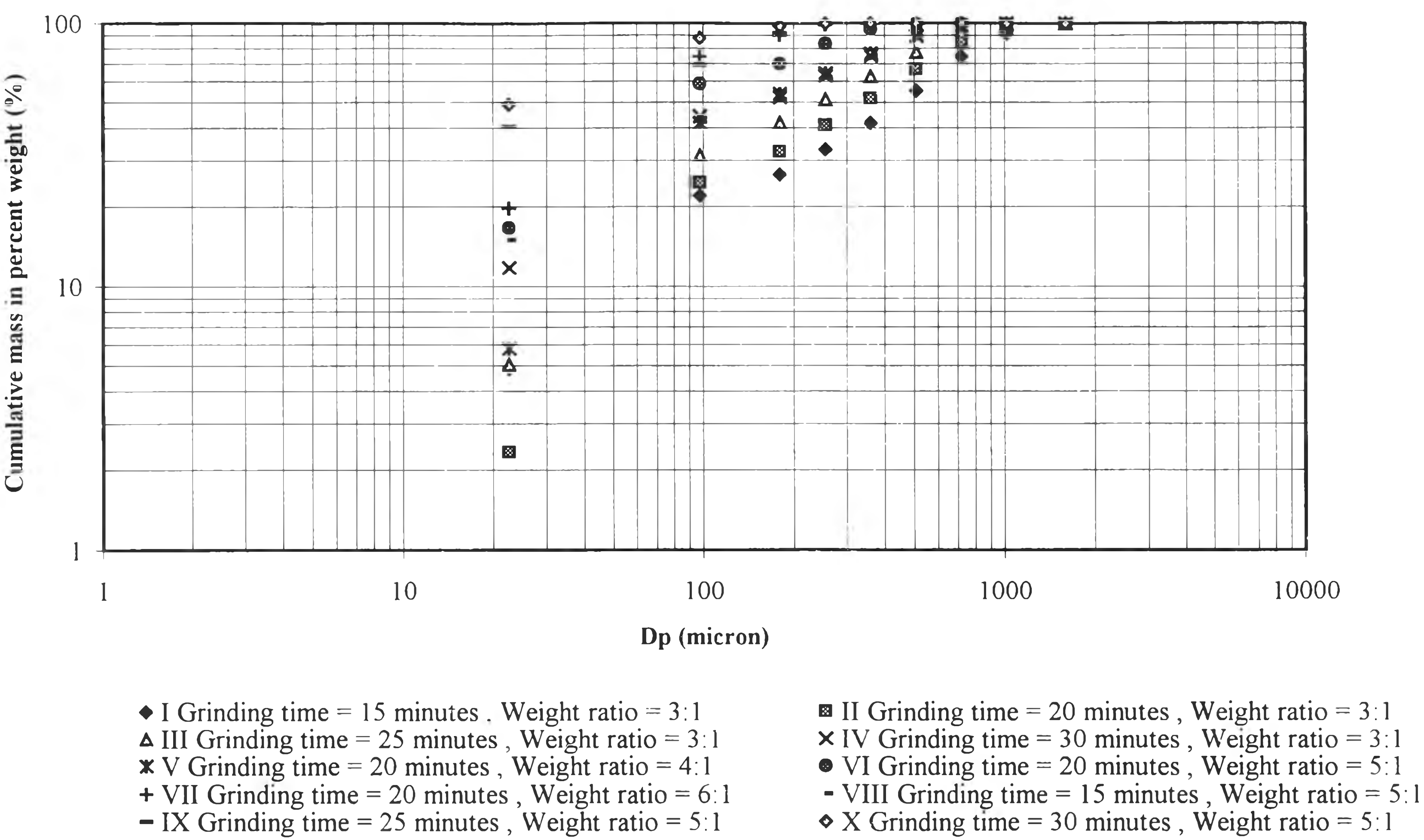


Figure 5.1 Size distribution of ground product obtained under various comminution conditions

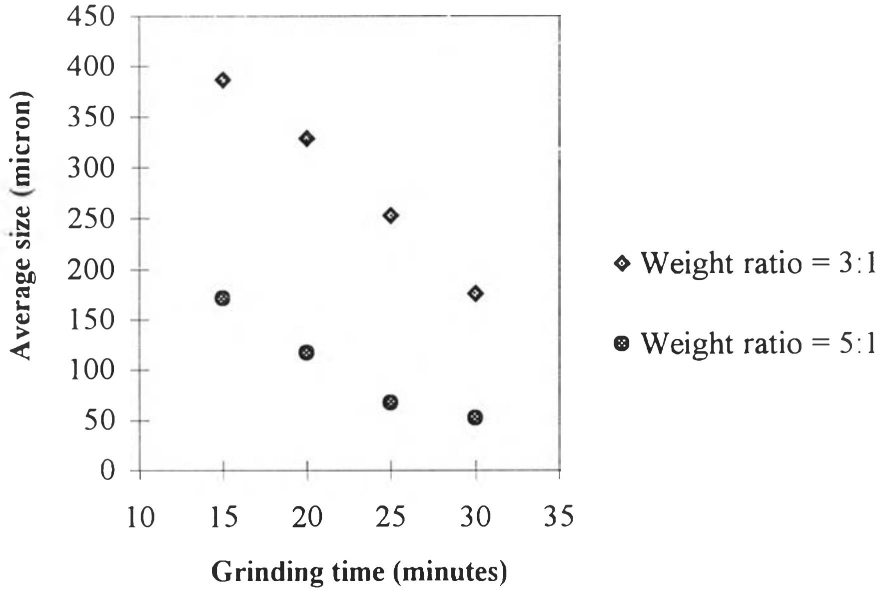


Figure 5.2 Relationship between grinding time and average size

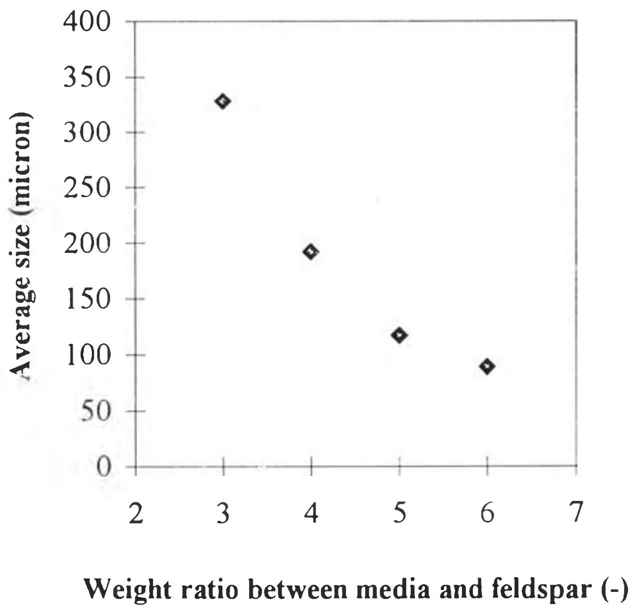
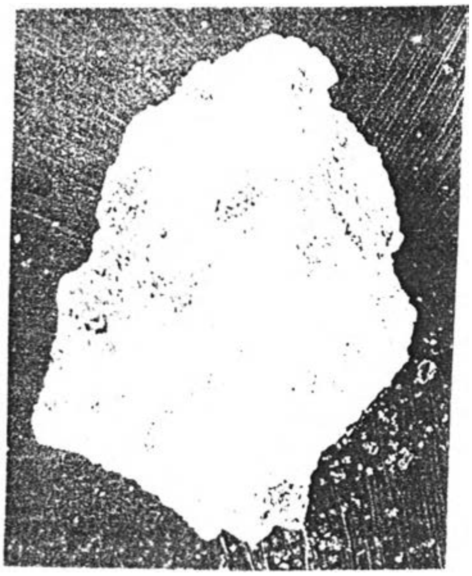


Figure 5.3 Relationship between weight ratio between media and feldspar and average size



Grinding time = 20 minutes,	Grinding time = 15 minutes,
Weight ratio = 4:1	Weight ratio = 5:1
Flow index = 80.50	Flow index = 83.00
Fractal dimension = 1.052	Fractal dimension = 1.047

Figure 5.4 Comparison of flowability of ground product in size range 149-210 micron

5.2 Effect of comminution conditions on the overall flowability

Because the size distribution characteristics of ground feldspar is insufficient to identify the difference of comminution conditions whose products have different flow characteristics but almost the same average size. Therefore the flowability of the ground feldspar must be taken into account for identifying the difference of its behavior.

The effect of grinding time and weight ratio between media and feldspar on the overall ground product are shown in **figure 5.5** and **figure 5.6** respectively. It can be seen that, the longer the grinding time or the higher the weight ratio between media and feldspar , the less the flowability. It can be explained that as the grinding time and weight ratio between media and feldspar were increased, the probability for particles to be ground became higher. This result is a decrease in the overall average size of ground product in comparison with those of particle before grinding. However, the flowability of overall ground product is affected by its size distribution. Therefore to study the effect of comminution conditions on flowability and particle shape , we must control the size of the ground feldspar by sieving the ground feldspar product into very narrow size ranges which are shown in the next investigation.

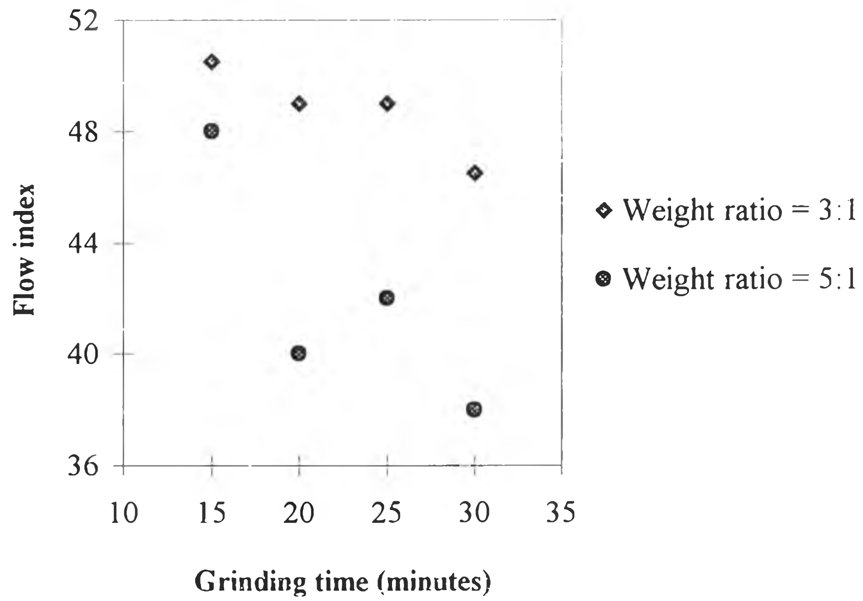


Figure 5.5 Relationship between grinding time and flowability of overall ground product

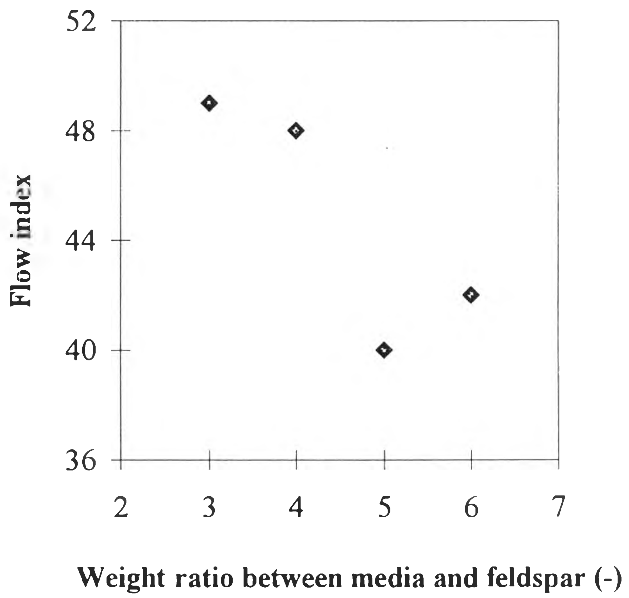


Figure 5.6 Relationship between weight ratio between media and feldspar and flowability of overall ground product (grinding time = 20 minutes)

5.3 Effect of grinding time on the flowability of classified product

The effect of grinding time on the flowability of ground products in three sizes ranges was investigated at 15,20,25 and 30 minutes. In order to control the effect of size on the flowability, the ground product was classified into three sizes ranges. The results are summarized in **table 5.1** when weight ratio between media and feldspar is 3:1 whereas the **table 5.2** for the case of weight ratio between media and feldspar is 5:1. **Figure 5.7** and **5.8** show relationship between flowability and grinding time of ground product in three sizes ranges for the case of weight ratio between media and feldspar is 3:1 and for the case of weight ratio between media and feldspar is 5:1 respectively.

From these figures, it is found that the flowability of ground product in each size range reaches it maximum value when the grinding time is 15 minutes and then decreases as the grinding time increases. In other words, the ground product which was ground for 15 minutes can flow easily and that for 30 minutes flows with difficulty. From these results together with observation on shape of the ground products, it could be inferred as an increase in shape irregularity of ground product due to the increased grinding time. To clarify this point, the particle shape of the ground product was taken into account.

Table 5.1 Effect of grinding time on the flowability of ground product (weight ratio between media and feldspar = 3:1)

Grinding Time (minutes)	**Size 149-210 micron**	**Size 210-297 micron**	**Size 297-420 micron**
15	78.00	86.00	81.50
20	78.00	84.00	81.00
25	77.00	83.00	79.50
30	77.00	83.00	79.50

Table 5.2 Effect of grinding time on the flowability of ground product (weight ratio between media and feldspar = 5:1)

Grinding Time (minutes)	**Size 149-210 micron**	**Size 210-297 micron**	**Size 297-420 micron**
15	83.00	86.00	83.00
20	78.00	83.50	82.50
25	82.00	86.00	-
30	82.00	-	-

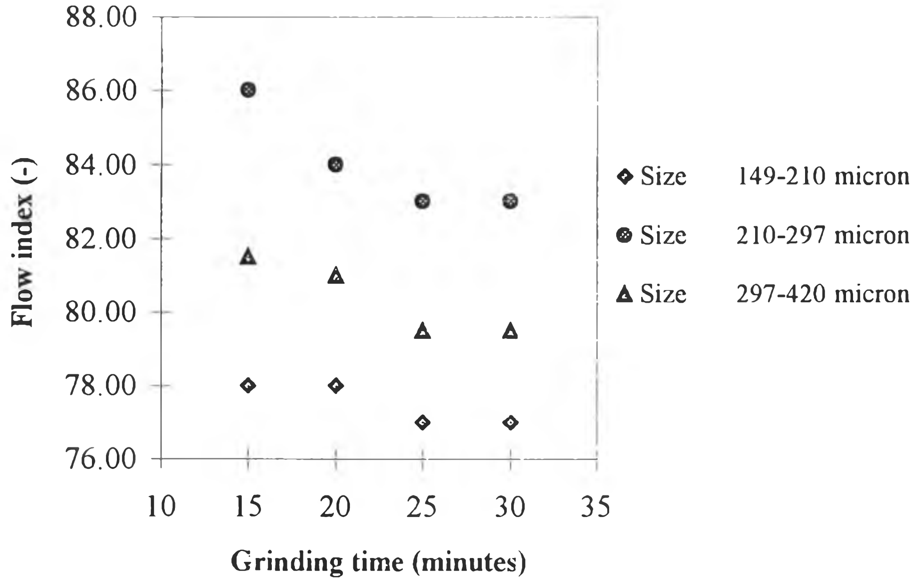


Figure 5.7 Relationship between grinding time and flowability in three sizes range (weight ratio between media and feldspar = 3:1)

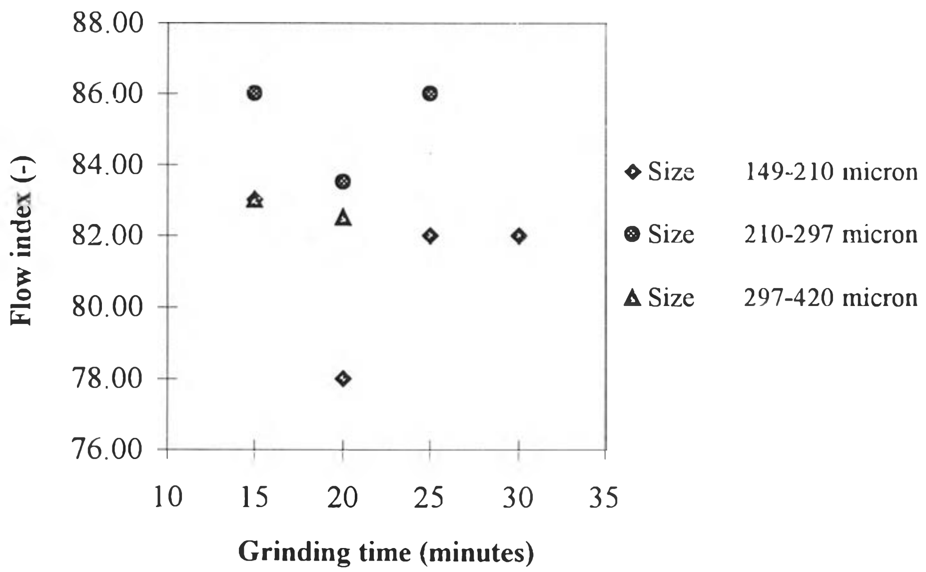


Figure 5.8 Relationship between grinding time and flowability in three sizes range (weight ratio between media and feldspar = 5:1)

5.4 Effect of grinding time on the particle shape

The effects of grinding time on fractal dimension (D), which is determined from count-based fractal analysis, are shown in **table 5.3** for weight ratio between media and feldspar 3:1 and in **table 5.4** for weight ratio 5:1. **Figure 5.9** and **figure 5.10** show relationship between grinding time and fractal dimension (D) for weight ratio between media and feldspar 3:1 and 5:1, respectively.

Table 5.3 Effect of the grinding time on the particle shape (weight ratio between media and feldspar = 3:1)

Grinding Time (minutes)	Fractal dimension 149-210 micron	Fractal dimension 210-297 micron	Fractal dimension 297-420 micron
15	1.063	1.064	1.044
20	1.054	1.069	1.044
25	1.055	1.071	1.050
30	1.064	1.076	1.051

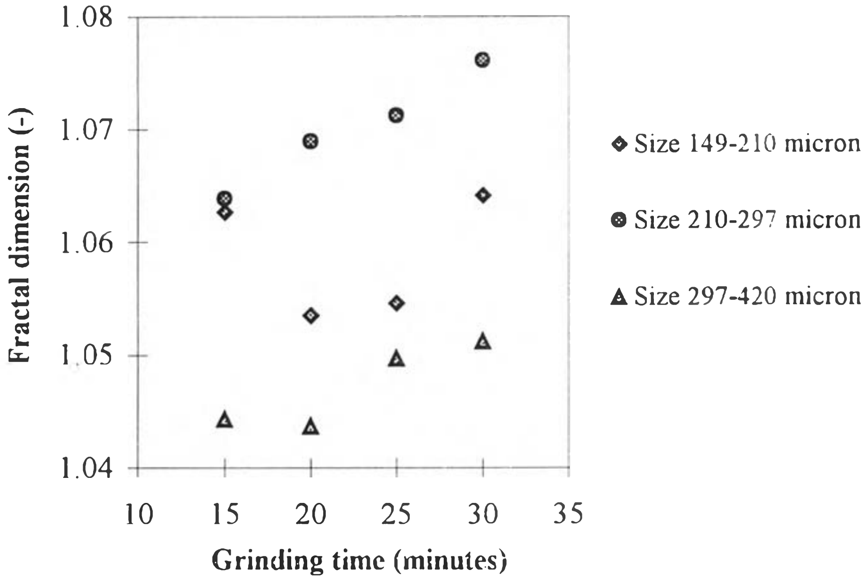


Figure 5.9 Effect of grinding time on the fractal dimension in three sizes ranges (weight ratio between media and feldspar = 3:1)

Table 5.4 Effect of the grinding time on the particle shape (weight ratio between media and feldspar = 5:1)

Grinding Time (minutes)	Fractal dimension 149-210 micron	Fractal dimension 210-297 micron	Fractal dimension 297-420 micron
15	1.047	1.051	1.035
20	1.050	1.048	1.043
25	1.054	1.051	1.055
30	1.042	1.051	1.044

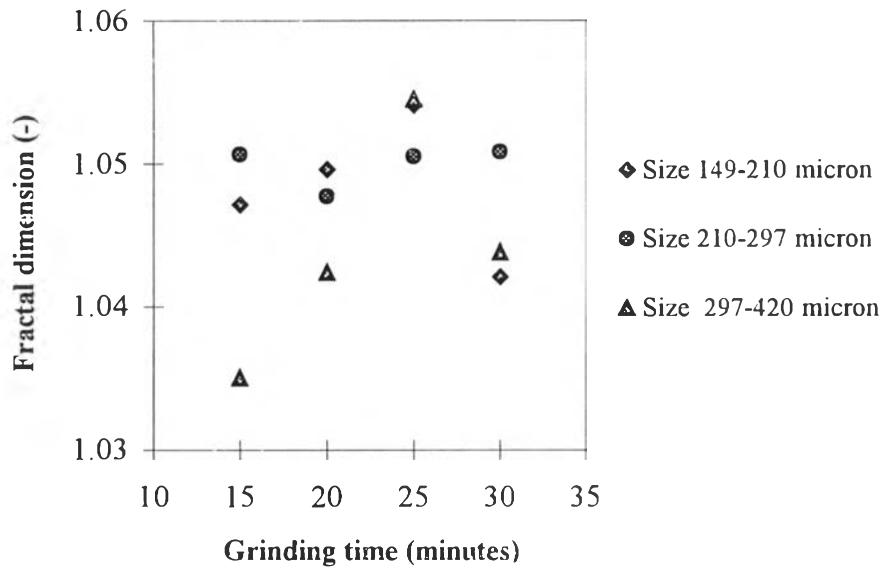


Figure 5.10 Effect of grinding time on the fractal dimension in three sizes ranges (weight ratio between media and feldspar = 5:1)

From **table 5.3** and **figure 5.9** , it can be seen that at weight ratio of 3:1 a trend of fractal dimension (D) representing the ground product shape irregularity increases with an increase in the grinding time. However, for the case of weight ratio of 5:1 the similar trend could be observed only when the size range was 297-420 micron. The higher the fractal dimension, the more complicated shape could be expected. Oshima (1995) also reported that in their experiment. Thus, from these results, it could be concluded that the shape irregularity increased as the grinding time increased. This conclusion supported the result of the relationship between the flowability and the grinding time mentioned previously.

5.5 Effect of weight ratio between media and feldspar on the flowability

The weight ratio between media and feldspar was investigated at 3:1, 4:1,5:1 and 6:1 to study its' effect on the flowability of ground product in three sizes ranges. The experimental data of flowability in each size range is shown in **tables 5.5** and shown graphically in **figure 5.11**

Table 5.5 Effect of weight ratio between media and feldspar on the flowability of ground product (grinding time = 20 minutes)

Weight ratio	Size 149-210 micron	Size 210-297 micron	Size 297-420 micron
3:1	78.00	84.00	81.00
4:1	80.50	87.00	82.50
5:1	78.00	83.50	82.50
6:1	76.00	81.50	-

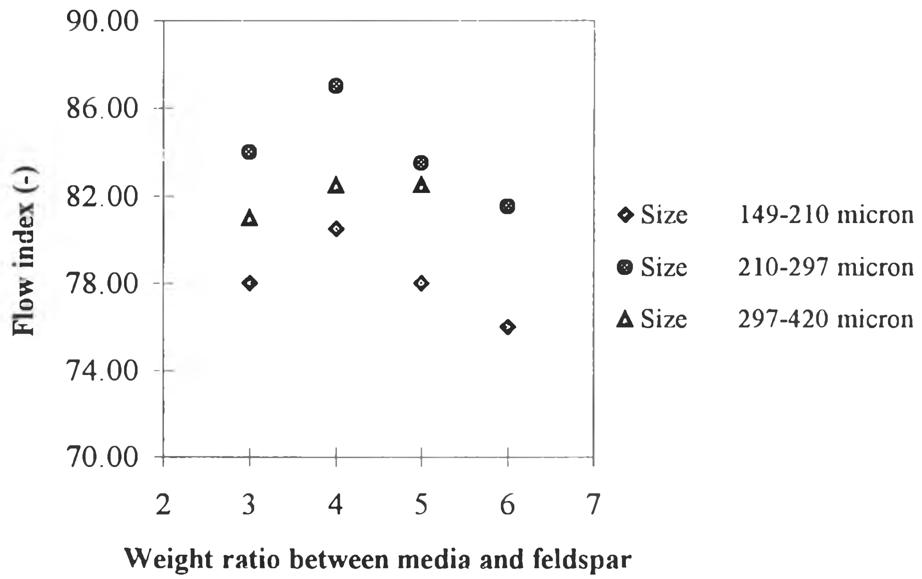


Figure 5.11 Relationship between weight ratio between media and feldspar and flowability in three sizes ranges (grinding time = 20 minutes)

From **figure 5.11**, it can be seen that at weight ratio between media and feldspar 4:1 the flow index, which represents the flowability of ground product reaches its maximum value. These results can be explained by considering the motion of media in the mill. If the mill contains more grinding media (which represents by higher weight ratio), the collisions between media and feldspar occur more frequently. This leads to cracking of particles which may cause the higher degree of irregularity of particle's shape. Therefore, the flowability of the ground product with the higher weight ratio becomes worse. On the other hand, if the mill contains less medias such as weight ratio between media and feldspar 3:1, the media and feldspar will collide more violently due to the less energy loss (Kousaka, 1973). This may result in more irregular shape of particles as well. Therefore at the weight ratio of 3:1, the ground product has smaller flowability than that of weight ratio of 4:1. From above results, it can be concluded that if the mill contains more or less grinding media, the ground product in each size ranges flows difficult. In other words, there would be an optimum weight ratio which will provide the ground product with the best flowability.

5.6 Effect of weight ratio between media and feldspar on the particle shape

The correlation between the weight ratio between media and feldspar and the fractal dimension (D) of ground product are summarized in **table 5.6**. **Figure 5.12** shows the graphical relationship between both variables.

Table 5.6 Effect of weight ratio between media and feldspar on the particle shape (grinding time = 20 minutes)

Weight ratio	Fractal dimension 149-210 micron	Fractal dimension 210-297 micron	Fractal dimension 297-420 micron
3:1	1.054	1.069	1.044
4:1	1.049	1.051	1.037
5:1	1.050	1.048	1.042
6:1	1.054	1.052	1.053

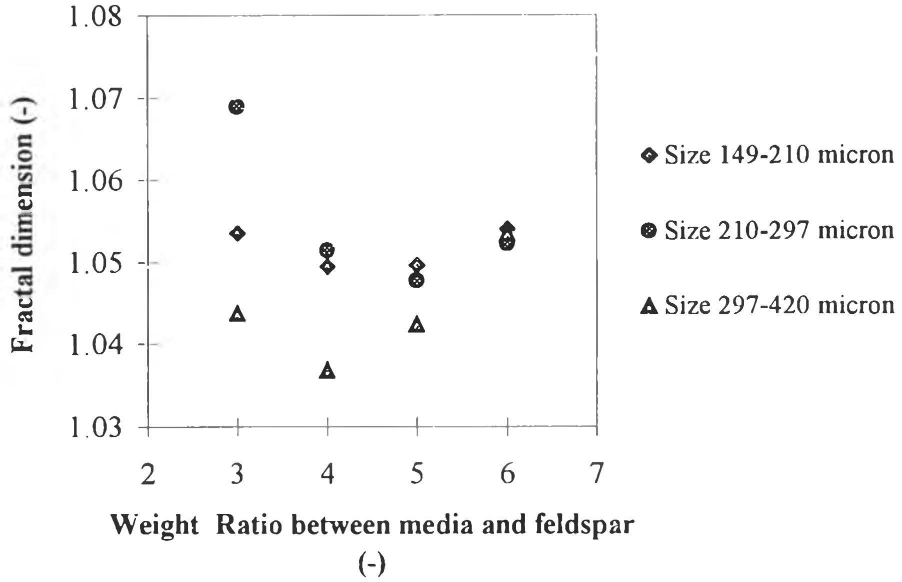


Figure 5.12 Effect of weight ratio between media and feldspar on the fractal dimension in three sizes ranges (grinding time = 20 minutes)

In **figure 5.12,** it can be seen that a trend of the fractal dimension (D) of the ground product obtained by weight ratio 4:1 shows a minimum value when the weight ratio is 4:1 for all classified cut sizes. These results agree with the relationship between the flowability of ground product and the weight ratio shown in **figure 5.11**. If the mill contains a more or less medias, the frequency of collision between media and feldspar or the violence of collision may lead to the higher degree of shape irregularity of ground product, which will be able to observe as the higher fractal dimension. Thus, from the effect of weight ratio between media and feldspar on the flowability and fractal dimension, it could be concluded that the shape irregularity of the ground product depend on the weight ratio between media and feldspar. With too much or too grinding media, the degree of shape irregularity of ground product would become higher.

5.7 Relationship between flowability and particle shape of ground product.

From the experimental results mentioned above, it could be found that the flowability and the fractal dimension of ground product had relatively relationship. The relationship between the flowability and the fractal dimension (D) is shown in **figure 5.13,5.14 and 5.15** for the sizes ranges 149-210 ,210-297 and 297-420 micrometers respectively. It is clear that the flowability of the ground product in each sizes ranges has a tendency to decrease with an increase in the fractal dimension (D). This means that the ground product with high shape irregularity or fractal dimension (D) does not flow well. This would be inferred to the surface friction on particles of rough surface. In other word, the higher the shape friction which is shown in term of fractal dimension (D) between the particles, the less flowability.

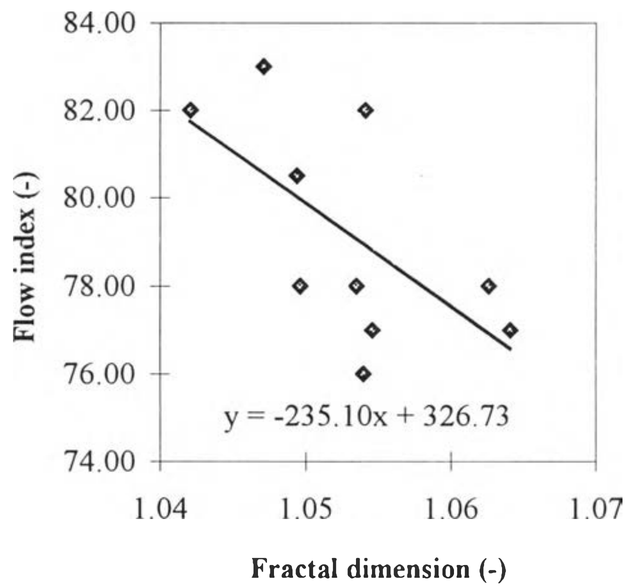


Figure 5.13 Relationship between the flowability and the value of fractal dimension of ground product in sizes ranges 149-210 micron

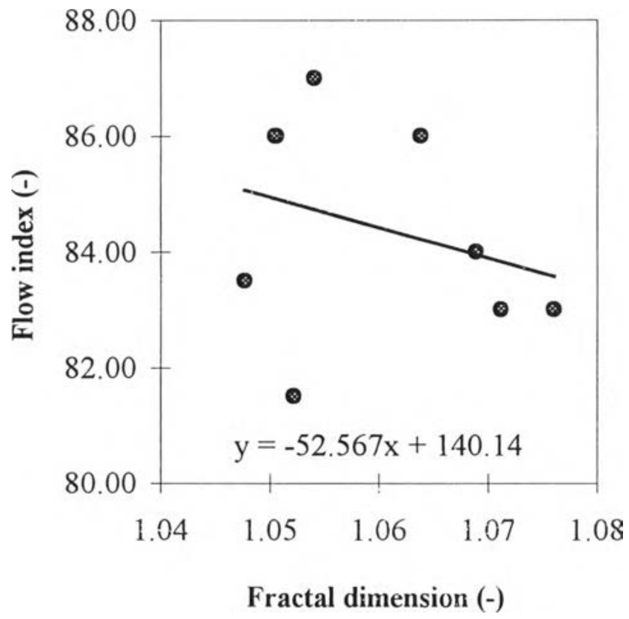


Figure 5.14 Relationship between the flowability and the value of fractal dimesion of ground product in sizes ranges 210-297 micron

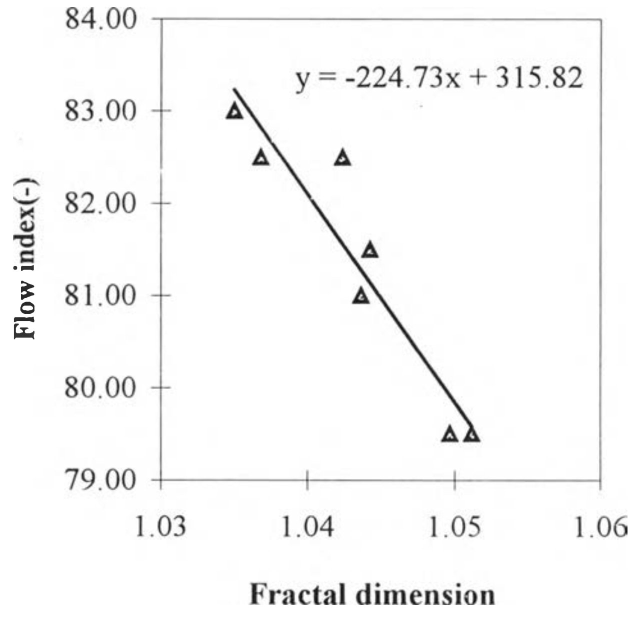


Figure 5.15 Relationship between the flowability and the value of fractal dimension of ground product in sizes ranges 297-420 micron

5.8 Analysis of variance for determining the difference of fractal dimension of ground feldspar

Applying method of analysis of variance, the author investigate the difference of fractal dimension among each ground feldspar obtained from different milling conditions. A typical example of analytical results is shown in **Table 5.7** for the ground feldspar of cut size between 210-297 micron. It can be seen that at the significance level of 10%, about 57% of fractal dimension of medium size ground feldspar obtained from different milling condition are different.

Table 5.7 Analysis of variance for determining the difference of fractal dimension of ground feldspar in sizes range 210-297 micron

	D(2)	D(3)	D(4)	D(5)	D(6)	D(7)	D(8)	D(9)	D(10)
D(1)	X	X							
D(2)	-	X							
D(3)	-	-	X						
D(4)	-	-	-						
D(5)	-	-	-	-	X	X	X	X	X
D(6)	-	-	-	-	-	X	X	X	X
D(7)	-	-	-	-	-	-	X	X	X
D(8)	-	-	-	-	-	-	-	X	X
D(9)	-	-	-	-	-	-	-	-	X

Remarks (shaded) = Fractal dimension are different

X = Fractal dimension are not differen

D(n) see appendix D

On the other hand, results of variance analysis of the fractal dimension of ground feldspar with different size but obtained from the same milling condition is shown in **Table 5.8**

Table 5.8 Analysis of variance for determining the difference of fractal dimension of ground feldspar in the same milling condition but different size

Grinding time = 15 minutes
Weight ratio = 3:1

	D(B)	D(C)
D(A)	X	
D(B)	-	

Grinding time = 30 minutes
Weight ratio = 3:1

	D(B)	D(C)
D(A)		
D(B)	-	

Grinding time = 15 minutes
Weight ratio = 5:1

	D(B)	D(C)
D(A)	X	
D(B)	-	

Grinding time = 30 minutes
Weight ratio = 5:1

	D(B)	D(C)
D(A)		
D(B)	-	

Remark
A : ground feldspar in sizes range 149-210 micron
B : ground feldspar in sizes range 210-297 micron
C : ground feldspar in sizes range 297-420 micron

From results of analysis, it was found that the fractal dimension of ground feldspar of each cut size from the same milling condition is different with the degree of significance of 10%