EFFECTS OF ROLL DIFFERENTIAL ON RECYCLE GRINDING SYSTEM IN FLOUR MILLING PROCESS: AT SECOND BREAK

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ABSTRACT

One of the key parameters in the flour milling process is roll differential, the relative speeds at which the rolls rotate. The roll differential causes the shearing action on the grain that removes bran from the endosperm. The aim of this study is to evaluate the recycle system at second break with the effects of roll differential. The effects of roll differential on a recycle grinding process in flour milling were investigated using a Satake STR-100 test roller mill. Differentials of each break-roll pair were adjusted to target differentials ratio (RD) of 2.0, 2.5, and 3.0 by changing the velocity of the slow roll. Fast rolls were set at a velocity of 550 rpm. Weight percentages for each particle size and ash content from the second break rolls to recycle system were examined. The results show of that changing the roll differential does affect the recycle grinding performance. Roll differential ratio 2.5 had significantly produced higher yield compared to 2.0 and 3.0 roll differential ratio. It was also concluded that the recycle grinding system was successful introduce at break system and could potentially produce the target production without compromising the quality of the finished product.

***Keywords**: ash content, recycle grinding, roll differential, roller mill, sieving*

INTRODUCTION

Flour milling is the process by which wheat is grounded into fine particles and through which the wheat grain is separated into its constituent parts: bran, germ and endosperm. The germ and bran are largely discarded while the endosperm is then further reduced into the fine powder that we call flour. Flour is a versatile and valuable food source that contains nutrients including vitamins. The best known use for flour is for making bread, but it also an important ingredient in biscuits, cakes, pies and much more. Majority of flour sold is white [1], this means it consists almost entirely endosperm. In recent years, about 54% of the total UK flour production was white flour which was used for breadmaking. This percentage is expected to rise further in the coming years [2].

In principle the milling process is established in three stages, which are break system, purification system and reduction system. The break system is used to break open the wheat kernel and continued to scrape endosperm from the bran, step by step, by sequential passages. The purification system is to separate the outer branny material from inner white endosperm. The aim of this purification system is to purify the milling material that almost no flour is produced. The reduction system is used to deliberately mill the center particles of the wheat grain into flour.

In conventional flour milling, the structure of the process and flow of the material streams are arranged in a very linear way (containing only inlet and outlet streams) and have very few combined streams. As a result, the milling process involves many unit operations. This is where engineers can be involved in improving the flour milling process, to reduce the number of operations, as there are likely to be streams that could be combined or recycled.

A typical concept in an engineering process is to incorporate processes with a recycle system. The function of recycle system is to recycle the ‘unreacted’ feed that effluent from the earlier steps in the process. The unreacted feed is usually too valuable to be disposed of and is therefore recycled to the earlier process. Thus, the study is to introduce this recycle concept into the flour milling process. It is expected that by introducing this concept the number of steps in typical flour milling process could be reduced.

Grinding is the most important process in flour milling. During the grinding process, many factors or parameters will have an effect on milling performance. One of the most important factors affecting the milling process is roll differential. Many researchers [3-7] who studied roll differential at first break, reduction systems and whole processes have suggested that roll differential influences the grinding release. A typical roll differential ratio that used in break system is normally 2.5[8] and for reduction system is 1.25[9-10].

This paper evaluates the recycle system with the effects of roll differential. It is expected to provide the optimum value of roll differential to the recycle process. In this paper, the scope of recycle study emphasizes mainly on the second break system.

MATERIAL AND METHODS

Type of wheat used was *Mallaca*, a hard wheat and moisture content of 10.23%. Wheat was milled in a Satake STR-100 Test Roller Mill and separated into certain size fractions. The STR-100 Test Roller Mill is a single pass, which uses full scale diameter rolls (250 mm diameter, 100 mm length) to mimic commercial flour milling operations. Roll gap was adjusted to 0.5 mm for the first break and 0.2 mm for the second break.

Three different roll speed differential' ratio (RD) were studied: 2.0, 2.5 and 3.0. Roll for the first break was fluted at 4 flutes/cm and the second break at 6 flutes/cm and operated in a dull to dull disposition. The raw material (wheat) was conditioned with moisture contents of 16%. Samples (wheat) were grounded on the first break rolls and had subsequently overtailed a 2000 µm sieve. Then, the feed for recycle grinding process was obtained from the second break system which overtailed from 2000 µm sieve aperture and repeatedly using it. Sieve analysis was performed on a Simon plansifter using the entire milled stock. Samples were sieved for 3 min using sieve stack comprising wire mesh sieves of size: 2000, 1700, 1400, 850, 500 and 212 µm. Eight classes of samples were collected at each of sieve tray, which the fraction over 2000 µm was at the top of sieve tray stack and the bottom was the fraction that passes through 212 µm apertures sieve.

The recycle grinding assessment was started after the second break system. The recycle grinding assessment was carried out using roller mill by simulating a steady state material mixture. The mixture was made up by taking the 2000 µm particle size fraction from each stage of the sequential grinding process and mixing them in their absolute proportions, which for this study the feed to recycle grinding was fixed to a certain amount. This process was repeated until third regrind (recycle). The series of experiments are illustrated graphically in Figure 1 and the simplified process is shown by block diagram in Figure 2.The American Association of Cereal Chemistry [11] methods were used for the ash analysis and moisture conditioning.

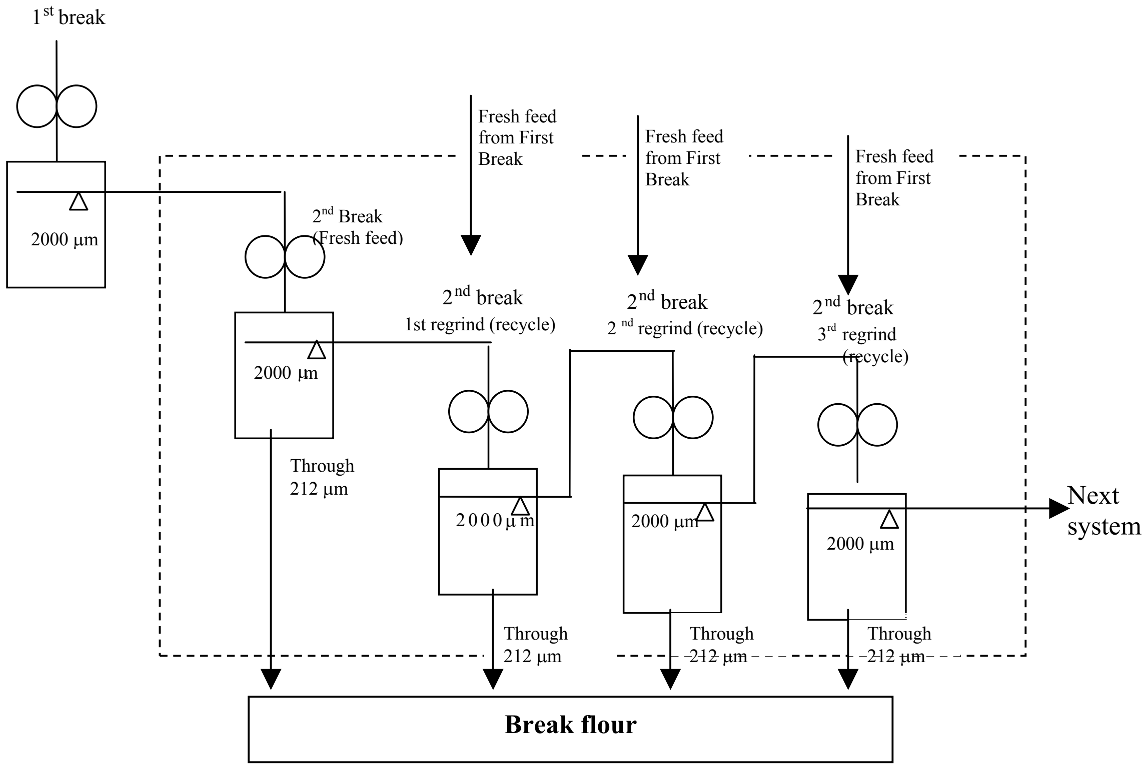


Figure 1: Schematic of the experimental grinding sequence. The same pair of rolls was employed for second break and each recycle successive stream.

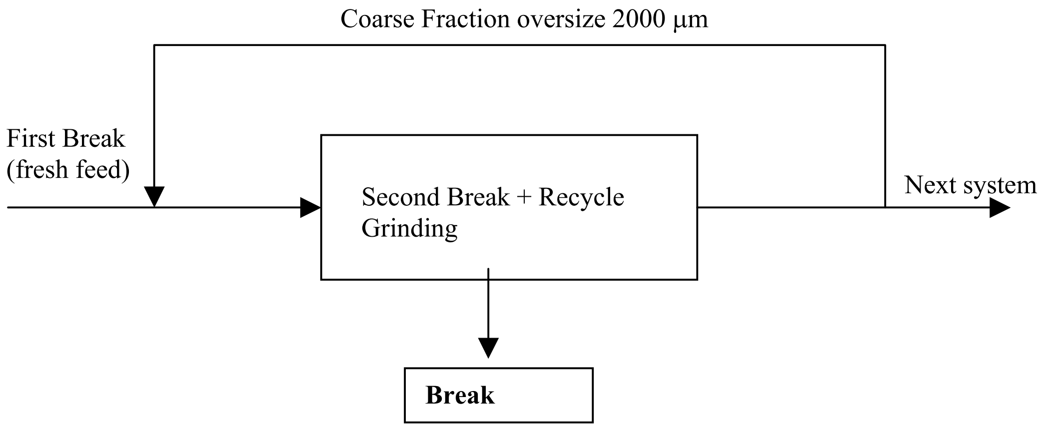


Figure 2: Block diagram for second break and recycle grinding process

RESULTS

The experimental works examine the recycle grinding behaviour in break system and were examined under three headings. There were particle size distribution, break release and ash content of the particles.

Particle Size Distribution

The particles obtained at the top of 2000 μm sieve tray from second break were sent to first regrind and repeated again up to three regrindings. The measurements of particle size for each class were then taken in order to determine material quantities released by the second break and recycle grinding system. The production of each size classification was measured and shown in Figure 3 with two different chart types. The figure on the left side visualises the results in bar chart form and on the right side shows the results in line pattern. This figure represents the results obtained from second break and recycle grinding system for wheat conditioned at 16% moisture content with three roll differential ratio (2.0, 2.5 and 3.0). The classes of particle size shown in the bar chart are analogous with the arrangement of the sieve trays that separated the grinding material. The fraction over 2000 μm was at the top of sieve tray stack and the bottom is the fraction that passes through 212 μm apertures sieve. Each line in the line chart represents each class of particle size.

Particles over a 2000 μm sieve predominated in all grinding systems for all three roll differentials. The fraction passing through 212 μm was less than 10% (total sample) for all three roll differential. The stocks released between 2000 μm and 212 μm would be sent to the next system which is to fine grinding or various purifiers for purification in preparation for reduction grinding. The weight percentage of each class of particle less than 2000 μm kept decreasing when the number of grindings increased.

Figure 4 (1) illustrates the effect of roll differential on particles over 2000 μm. It shows that weight percentage for this fraction kept increasing from second break to third recycle at RD 2.0 and 2.5. However, for roll differential ratio 3.0 the weight percentage remains constant when it achieved second recycle to third recycle grinding. RD 2.5 significantly produced high yields compared to 2.0 and 3.0.

The quantity of material released for fractions below 212 μm (Figure 4(2)) gave the opposite results than that for the fraction over 2000 μm (Figure 4(2)). RD 2.5 resulted in a lower weight percentage for fraction 212 μm for the second break and recycle grinding system. At this fraction, for all roll differentials, the weight percentage remains slightly constant from second recycle to third recycle grinding. When changing RD from 2.0 to 2.5 (for all grindings), the material quantity over 2000 μm increases and material quantity for below 212 μm decreases as the number of recycles increases. In contrast, from 2.5 to 3.0, the quantity over 2000 μm suddenly decreases and the quantity below 212 μm increases.

Inconsistent results were obtained for the particle size distribution when changing the roll differential. It is expected that at high roll differential, where the speed ratio between fast roll and slow roll is higher, more corrugations will pass each other at a given time. This will increase the shearing and scraping of the particle (bran and endosperm) and this should result in more endosperm particles and finer bran fragments, and less coarse (bran) particles. This means the particle size distribution for particles over 2000 μm should tend to decrease and particles less than 212 μm should tend to increase as roll differential increases. However, the results presented in this section show different phenomena.

Break release

The break releases by recycle process were calculated to determine the amount of material that would be sent to the next system (purification and reduction). Break release for this recycle process was calculated from the percentage of material that passes through a 1180 μm sieve. Break release for the entire roll differential was obtained and Table 1 details the results.

Table 1: Break release by recycle process for the entire roll differential

Grinding/Roll Differential	2.0:1	2.5:1	3.0:1
Second Break	48.78	43.84	46.36
First Recycle	46.02	38.40	44.74
Second Recycle	43.59	36.24	43.36
Third Recycle	41.87	36.16	36.66

Break release for the entire roll differential kept decreasing as the number of grindings increased. However, the rate of decrease of break release at RD 2.5 from second recycle to third recycle seems nearly constant and might achieve steady state level. In contrast, from RD 2.0 and 3.0, it still decreases progressively from second recycle to third recycle. When changing roll differential ratio from 2.0 to 2.5, break release was decreased and increased again from RD 2.5 to 3.0. The amount of break release was the lowest at RD 2.5 between those roll differentials.

Ash Analysis

Ash content was analysed using the laboratory oven (furnace) method. Ash content of each size classification separated was measured. Figure 5 represents the results obtained from the recycle grinding system with three series of roll differential and the wheat conditioned at 16% moisture content. It shows the quality of material released from the recycle grinding system. In general, ash content was greatest when milled with a RD 3.0 and least with RD 2.0 (Figure 5). There was significant difference in ash content between particles above 850 μm and particles below 850 μm. The ash content for particles over 850 μm sieve was above 1.5% and less than 1% for particles below 850 μm.

Figure 6 gives the results for size particles above 2000 μm and below 212 μm. For particles over 2000 μm (Figure 6(1)), as the number of recycles increased ash content increased. Increasing roll differential also increases ash content for each grinding of this particle stream (>2000μm). The RD 3.0 produced the highest results for this particle size. Typically, the quality of this particle size becomes poorer as the number of recycles and the roll differential increases.

The ash content for the particles passed through 212 μm sieve was not consistent in this series of roll differentials. As for RD changing from 2.0 to 2.5, the percentage of ash content decreased with increasing recycle grinding numbers. In contrast with RD 3.0, ash content kept increasing (0.42% to 0.59%) as the number of recycles increased.

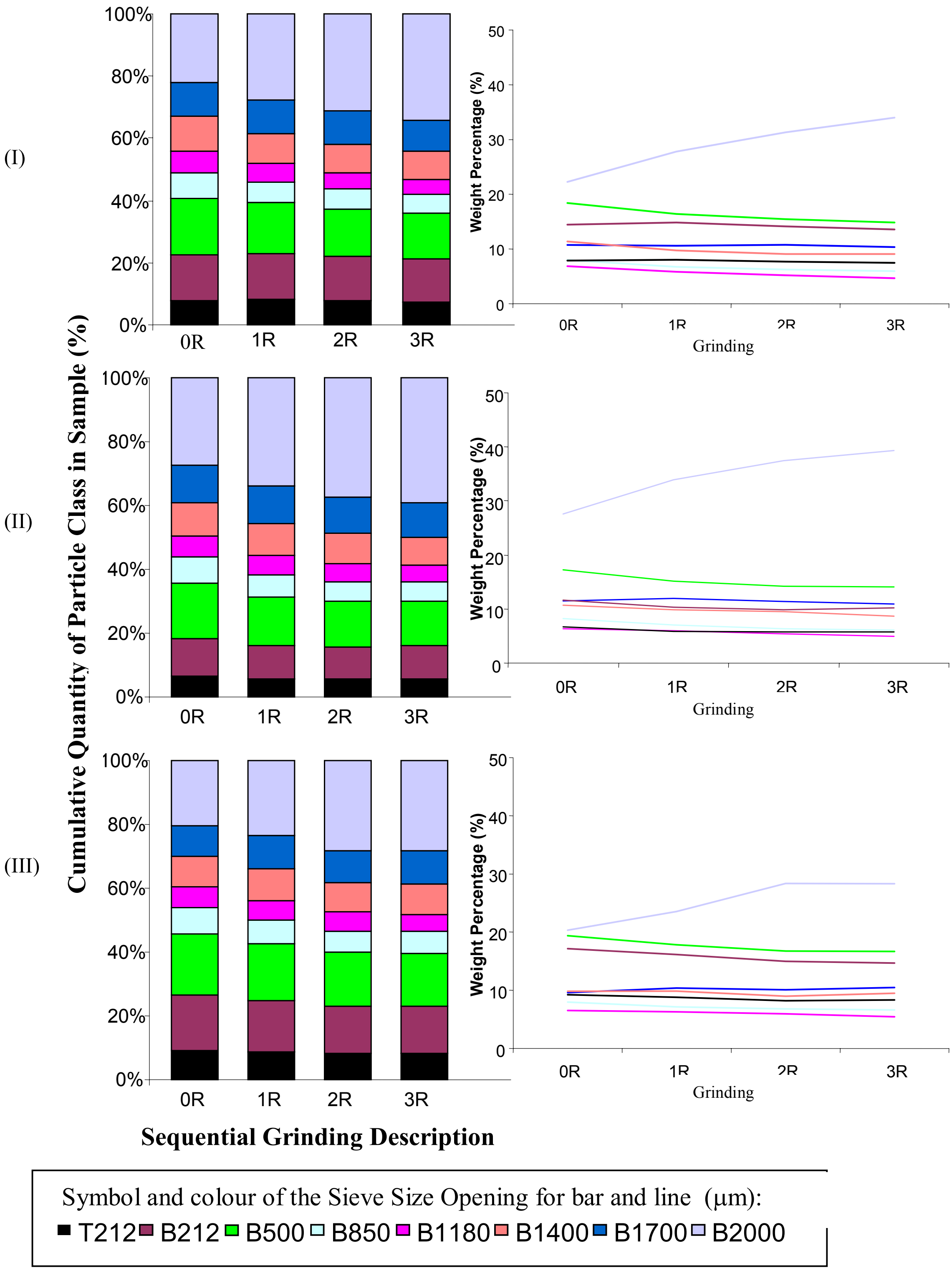
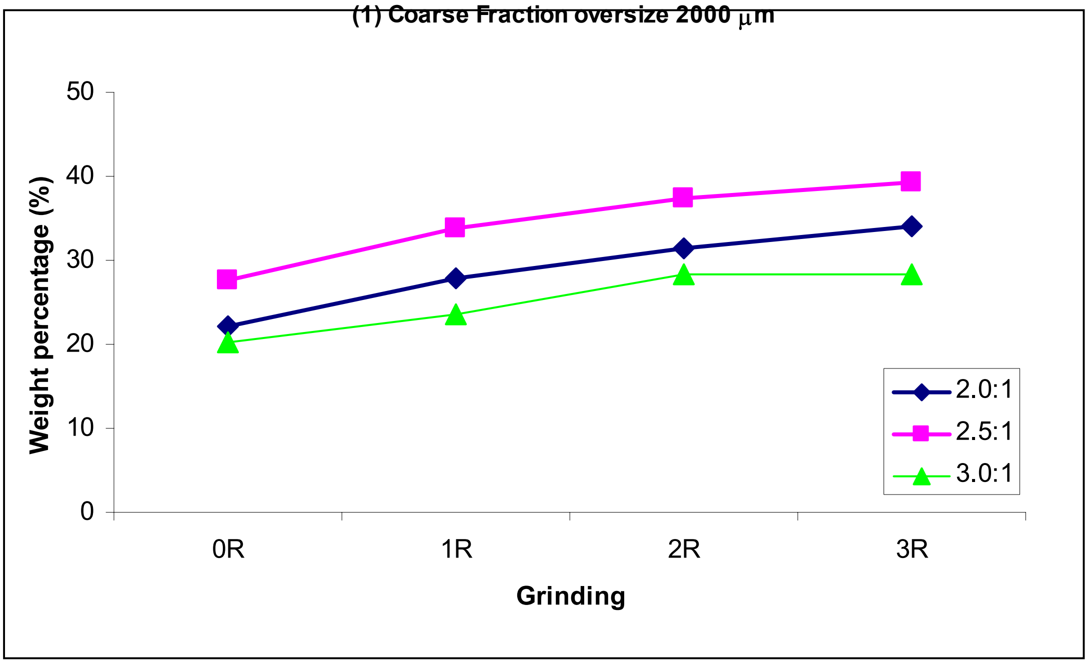


Figure 3: Effect of roll differential ratio on particle size distribution from Second Break and Recycled (At Moisture Content 16%) (I) RD 2.0 (II) RD 2.5 (III) RD 3.0



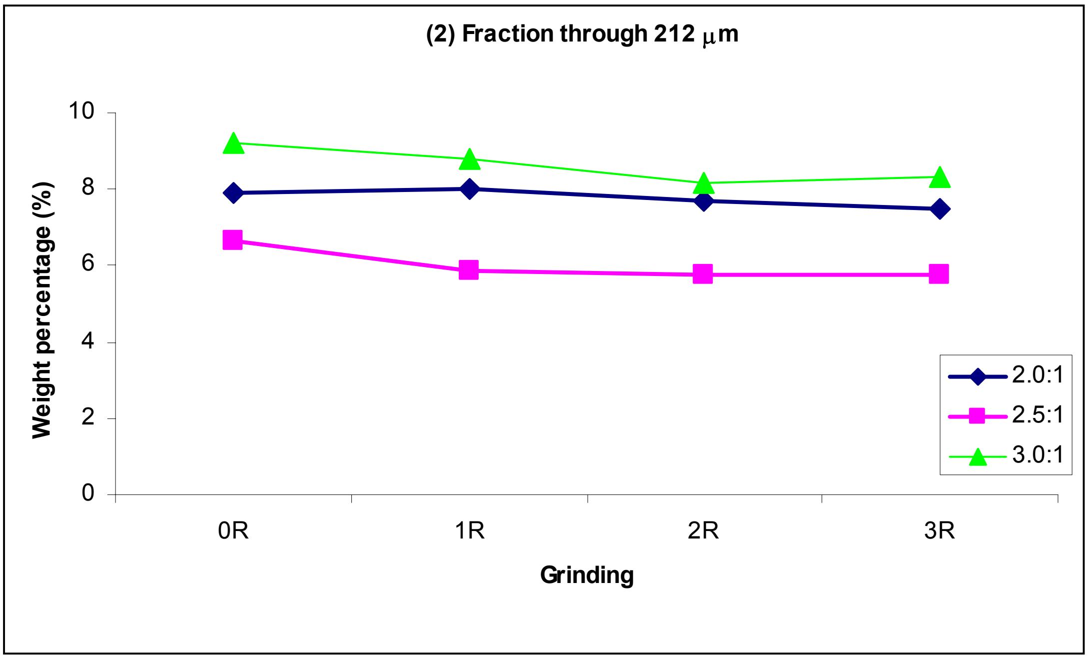


Figure 4: Effect of roll differential on grinding performance with moisture content 16% (1) The course fraction oversize 2000µm (2) The fraction through 212µm

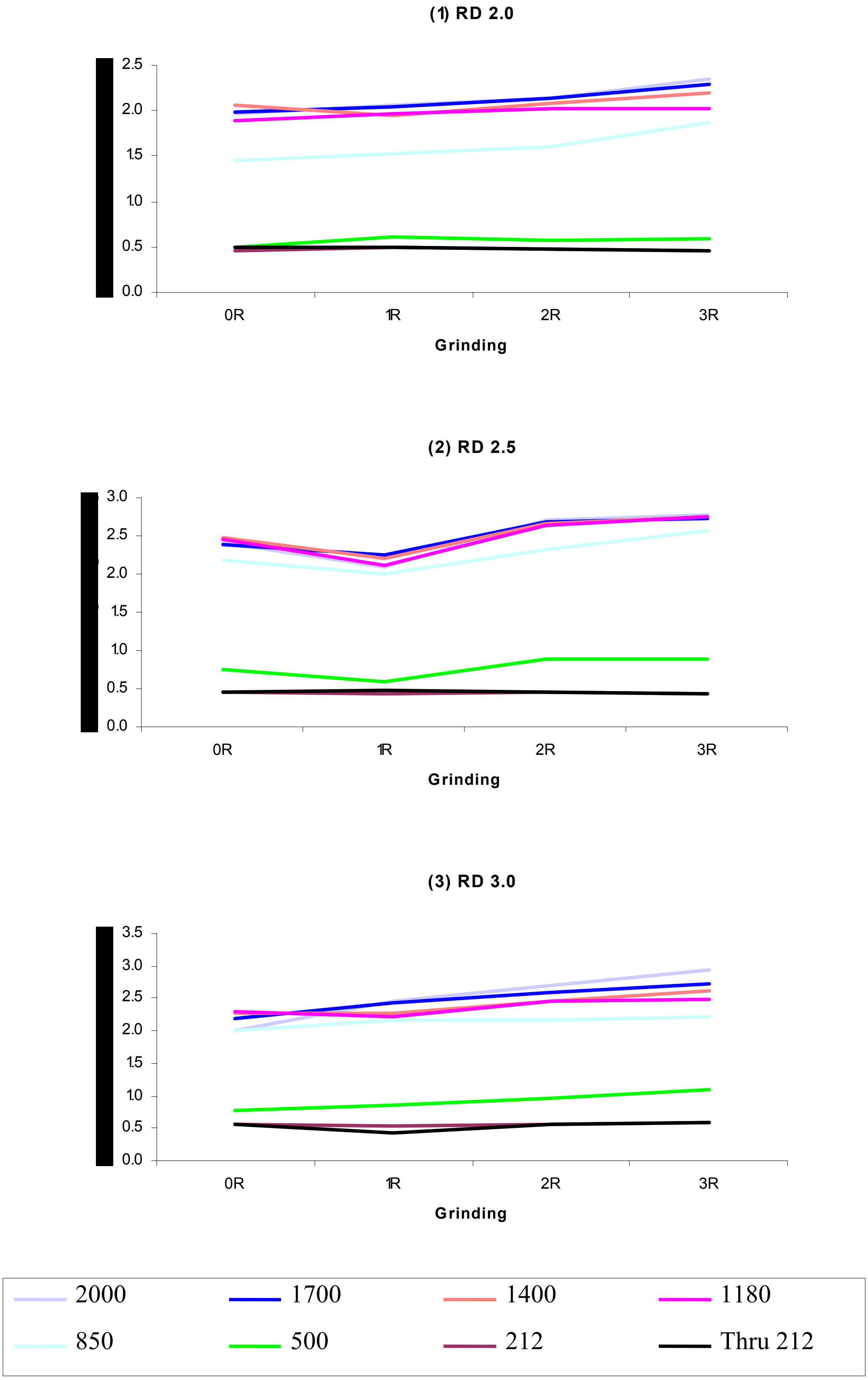


Figure 5: Ash content of size fractions for Second Break and Recycle Grinding at moisture content 16%;(1) RD 2.0 (2) RD 2.5 (3) RD 3.0

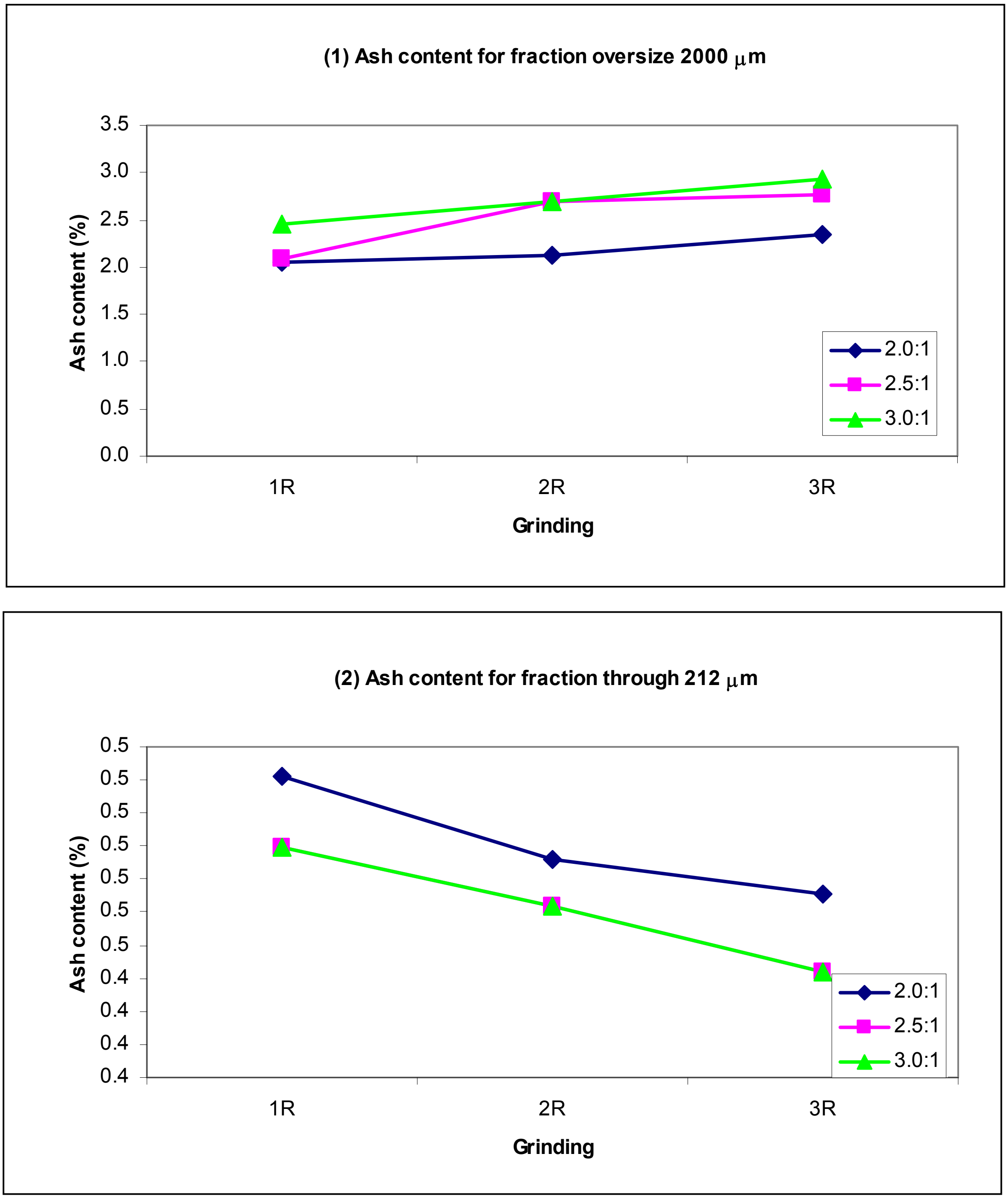


Figure 6: Ash content for recycle grinding system at three roll differential (1)Fraction over 2000μm (2) Fractions passes through 212μm sieve

DISCUSSIONS

Table 2 shows the rate of percentage for three-roll differential, from second recycle to third recycle. It is the main concern to find at which point the grinding process will achieve steady state level.

Table 2: Percentage change in various stream properties between second and third recycle.

RD		***2.0***	***2.5***	***3.0***
Weight collected	Over 2000μm	8.5%↑	4.8%↑	28.8%↑
	Through 212μm	3.0%↓	0.3%↓	14.1%↓
Break release		3.9%↓	0.2%↓	15.4%↓
Ash content	Over 2000μm	10.3%↑	2.6%↑	8.9%↑
	Through 212μm	2.1%↓	2.0%↓	5.3%↑

- ↑ *- indicates increase and* ↓ *- indicates decrease*

From Table 2 above, grinding from the entire roll differentials still progressively produced particle size >2000 μm and kept decreasing the percentage of particle size <212 μm until third recycle. Rate of percentage produced for coarse particle (>2000 μm) was high at RD 3.0 and lowest at 2.5. The RD 3.0 produced the highest rate of decrease for particle size <212 μm and RD 2.5 had the lowest results which seemed nearly constant or achieved steady state level. Similarly for break release, RD 2.5 shows the lowest rate of decrease, with the percentage of break release at third recycle being 36.16%, slightly lower than RD 3.0 at 36.66%, with RD 2.0 giving the highest result, at 41.87% of break release (refer to Table 1 for break release percentage for entire roll differentials). Both results (from weight percentage and break release) indicate that RD 2.5 seems to nearly achieve steady state after second recycle.

For ash content, the rate of increase for particle >2000 μm was highest at RD 3.0 and lowest at RD 2.5. For the ash content percentage at third recycle, RD 2.0 was 2.35%, RD 2.5 was 2.77% and RD 3.0 was 2.94%; all the results were below 3.0% (refer to Figure 6(1). For particle <212 μm, at RD 2.0 and 2.5, rate of percentage of ash content from second to third recycle decreased while for RD 3.0 it still kept decreasing. Between those roll differentials, ash content at third recycle was the lowest at RD 2.5 being 0.44%, with 0.45% for RD 2.0 and 0.59% for RD 3.0.

From all the results, RD 2.5 was chosen as the best value for the recycle grinding process because:

(1) The quantity of the break release became nearly steady state level after the second recycle.
(2) The ash content of particle <212 μm was the lowest amongst the three roll differentials.
(3) Increasing the number of grindings also makes the quality of particle <212 μm better compared with other roll differentials.
(4) The weight percentages of particles >2000 μm and <212 μm were the highest and lowest respectively, similar to the ash content results. This means that at this roll differential, cleaner separation happened between endosperm and bran. Although the weight percentage of particles <212 μm produced was the lowest, the main concern is the quality, and the particles <212 μm produced was contaminated with a very small amount of bran compared to particles produced by other roll differentials. The amount of particles <212 μm produced by other roll differentials might contain more fine bran, which reduces the amount of coarse particles. This has been proven by the result that shows that the fine particles produced for RD 2.0 and 3.0 contain more ash (indicates more bran).

<u>*Overall comment on the recycle system:*</u>

(1) The quality of the larger particles was progressively poorer as the number of recycles increased. This indicates a progressively cleaner separation of endosperm and bran.

(2) There was definite differentiation between the quality of larger (above 2000 µm) and smaller particles (below 212 µm) through the range of the recycle system. These may verify that the break and recycle system successfully separates the bulk of the bran from the endosperm.
(3) The ash content obtained was low and well within the normal expectation for this recycle grinding process.

Based from the above points it might be possible that for each regrind the recycle particle might still contain endosperm. However, after each cycle the recycle particle might contain less endosperm which this could contribute to increase the ash content.

The value of ash content for recycle particle was still considered low (less than 3%) after regrind it up to three recycle. This could mean that more endosperm still attach and might still economical to separate it for the next regrind.

Based on ash analysis, the quality for particles above 850µm becomes poorer for each regrind. This maybe explained by the fact that the recycle particles (>2000 µm) with less endosperm (contain more or only bran) being returned for regrind were broken into smaller particles but not fine enough to pass through 850µm. This means that the broken bran fragments were being distributed to other classes of particle above 850µm. This is also being supported by the ash content results for particle size less than 850µm which slightly decreased (became better) as the number of recycles increased. This mean that the quality of break flour (<212µm) might not be affected when increase the number of recycle.

CONCLUSION

2.5 roll differentials were chosen as the optimum value to grind the Mallacca wheat for the recycle grinding system. Changing the roll differential does affect the recycle grinding performance. This also means that the output breakage pattern for recycle grinding system is functioned to roll differential. Thus, providing the optimum value is meaningful in order to obtain an optimum output percentage of break release. Finally, it was concluded that the recycle grinding system was successfully introduced at break system and could potentially produce the target production without compromising the quality of the finished product.

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