UNIVERSITI PUTRA MALAYSIA

MECHANICS OF RICE GRAIN DUE TO MILLING PROCESS

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ABSTRACT

This research were conducted to determine the effects of drying conditions and moisture contents on the mechanical properties of MR 220 rice variety and analyze the fissure formation in the rice kernels after drying using scanning electron microscope. The samples were dried at 40°C to 90°C for 5 hours of drying. After drying, the rice were subjected to compression test and three-point bending test. The breaking force values for both tests showed that lower breaking force at highest temperature (90°C) which is 74 N and 8.78 N for compression and three-point bending test, respectively. However, from the results it showed that temperature has no significant effect on breaking force in compression test compare to three-point bending. It was further indicated that, at higher temperature the breaking displacement is lower which are 0.316 mm and 0.079 mm for compression and three-point bending tests, respectively. For effect of moisture contents on the breaking force, both compression and three-point bending test showed highest breaking force at MC of 10% d.b. which are 77 N and 30 N, respectively. Breaking displacement for both tests showed different results where the highest breaking displacement occurred at MC of 17% d.b. which is 0.39 mm for compression test. However, results from three-point bending indicated that the highest breaking displacement occurred at MC of 10% d.b. which is 0.19 mm. Therefore, compression test is no the best option to study the mechanical properties of rice kernel. From photomicrograph of SEM, most and the largest fissures were developed at the highest temperature which is at at 90°C which proved that rice kernel easy to crack at higher temperature. Thus, it that proved severe drying has significant effect on fissure formation of rice grains.

ABSTRAK

Kajian ini dijalankan untuk mengesan kesan keadaan pengeringan dan kandungan kelembapan pada sifat mekanik beras dan menganalisis pembentukan rekahan dalam beras MR220selepas pengeringan dengan menggunakan mikroskop elektron imbasan. Beras dikeringkan pada 40°C sehingga 90°C selama 5 jam pengeringan. Selepas pengeringan, beras itu tertakluk kepada ujian mampatan dan ujian lenturan tiga mata. Nilai daya pecah bagi kedua-dua ujian mampatan dan lenturan tiga mata menunjukkan bahawa daya pecah lebih rendah pada suhu lebih tinggi iaitu 74 N dan 8.78 N. Walau bagaimanapun, hasilnya menunjukkan bahawa suhu tidak mempunyai kesan yang ketara ke atas daya pecah dalam ujian mampatan berbanding dengan lenturan tiga mata. Ia juga menunjukkan bahawa anjakan pecah lebih rendah pada suhu lebih tinggi iaitu 0.316 mm dan 0.079 mm untuk ujian mampatan dan ujian lenturan tiga mata. Untuk kesan kandungan lembapan pada daya pecah, ujian mampatan dan lenturan tiga titik menunjukkan bahawa daya pecah tertinggi pada MC 10% d.b. yang masing-masing adalah 77 N dan 30 N. Pemotongan perpecahan untuk kedua-dua ujian menunjukkan keputusan perbezaan di mana anjakan pecah tertinggi terjadi pada MC sebanyak 17% d.b. iaitu 0.39 mm pada ujian mampatan sementara lenturan tiga titik menunjukkan bahawa anjakan pecah tertinggi berlaku pada MC 10% d.b. iaitu 0.19 mm. Oleh itu, ujian mampatan bukan pilihan terbaik untuk mengkaji sifat-sifat mekanik kernel beras. Dari photomicrograf SEM, hasil menunjukkan kebanyakan rekahan terbentuk pada suhu tertinggi iaitu pada suhu 90°C yang membuktikan bahawa kernel beras mudah pecah pada suhu yang lebih tinggi. Oleh itu, terbukti pengeringan teruk mempunyai kesan yang signifikan terhadap pembentukan rekahan beras.

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d.b.	Dry basis
DOM	Degree of milling
FAO	Food and Agriculture Organization of the United Nations
IRRI	International Rice Research Insitute
MARDI	Malaysia Agricultural Research and Development Institute
MC	Moisture Content
w.b.	Wet basis

CHAPTER 1

INTRODUCTION

1.1 Background

Rice (*Oryza sativa L)* is the grass species with mostly consumed staple food for nearly one half of the world's population (Lu, 1998) with Asia is being the largest producer and consumer. It is cultivated in many countries such as India, Thailand, Argentina, Pakistan, China, Brazil, Thailand and Indonesia. In Malaysia, rice is considered as one of the most important crops in domestic agriculture, though the trend of consumption of rice per capita is decreasing from 93 kg per capita in 2011 to 88.9 kg per capita in 2014. Malaysians adult population consumed an average of two and a half plates of rice per day (Norimah Jr, 2008) from the food consumption pattern analysis. The domestic rice production in Malaysia is declining despite the demand for rice from the population in Malaysia (Khalid *et al*, 2015). Thus, to avoid shortage of rice in the future Malaysia government had imported the balance from major rice producing countries, mainly from Thailand.

As shown in Figure 1.1, the paddy-rice grain structure consists of an outer protective layer which are the hull and the rice caryopsis or in other word dry fruits (brown, cargo or dehusked rice). Brown rice consists of the outer layers of pericarp, seed-coat and nucellus, the germ or embryo, and the endosperm. About 20% of the rough rice weight is the husk and the distribution of brown rice weight is pericarp (1 to 2 percent), aleurone plus nucellus and seed-coat (4 to 6 percent), germ (1 percent), scutellum (2 percent) and endosperm (90 to 91 percent) (Juliano, 1972).

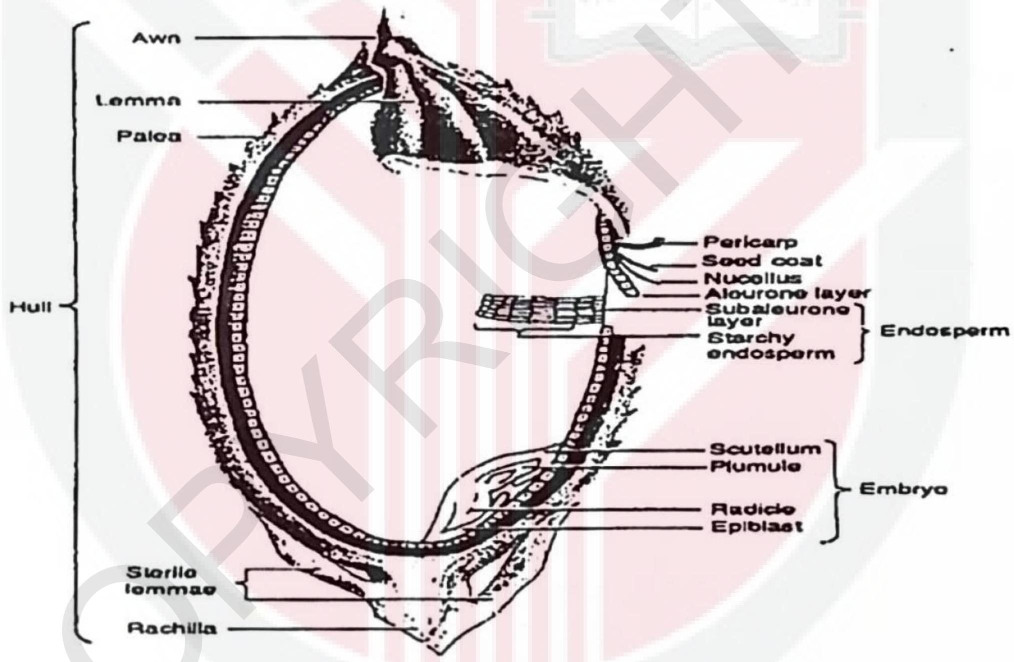


Figure 1.1: Longitudinal section of rice grain

There are many types of rice in the world with different shapes, size and texture or any other characteristics that affect how the rice will be cooked at the end. In the world market of rice as well as in Malaysia, most consumers much emphasis the size of the grain ranging from long and slender to the short and tubby and also the whiteness of the end product of rice a the main criteria of the grade and quality. According to IRRI

(International Rice Research Insitute), they use the following standard to determine the size of rice grain which are extra-long (>7.50 mm), long (6.61 to 7.50 mm), medium (5.51 to 6.60 mm) and short(<5.50 mm). Consumers in Malaysia preferred rice with long and slender size the most (MARDI Res. Bull.,1984). Types of rice in the world market are long grain rice, white rice, brown rice, Basmati rice, and Jasmine rice. Types or properties of rice are dependent on how the rice is processed, either well-milled or semi-milled. Most of the consumers, including Malaysian consumer preferred white rice where the rice is well-milled with no bran remaining on the endosperm.

Rice grains possess hygroscopic behavior that will readily gain or loss water when it reacts to moisture content and temperature changes in the environment. The drying process will induce internal fissure of rice kernel and reduce the mechanical strength of rice kernel especially in high temperature due to rapid decrease in moisture content. Thus, it will cause rice breakage during milling and reduce the head rice yield. Fissures forms when internal hygroscopic stress are exceeded by the internal stress that is induced by the moisture content created during drying (Jia *et al.*, 2002; Sarker and Kunze, 1996).

Production of rice with minimum breakage during rice milling has always been the primary goal for most rice industries because removing the husk and bran layers will improve the appearance, cooking quality and palatability of rice. Thus, it is very important to have the information on mechanical properties of rice grains to analyze the breaking behavior during handling and processing. The major mechanical properties of rice grains that have been studied and investigated including the tensile strength, compressive strength and bending strength (Zhang *et al.*, 2005). In addition, to design accurate of handling milling machinery with different levels of moisture content is necessary to minimize the rice breakage. Chattopadhyay *et al.* (1981) showed that moisture content had a great influence on the mechanical properties of high starch grain based on compression test. The rheological behavior showed that, as the moisture content increase, the viscoelastic relaxation modulus increased with time decreased.

1.2 Problem Statement

Fundamental studies on mechanical properties of the rice grain are important to make the operations involved in rice processing more effective and efficient. By knowing the mechanical properties of rice kernels, their cracking behaviours during handling and processing can be predicted and analyzed. The rice industry at all levels is seeking to develop new and better equipment to do specific tasks faster and with greater accuracy especially in a milling operation. The quality of milled rice is the most important parameter in rice industry because it will determine the economic valued of rice. Milling quality loss is of great concern results from individual grains that break.

Many research has been conducted to understand the formation of fissures under drying research and various drying process have been used such as heated-air, multipass drying of high-moisture, and single-pass drying. Fissure is a small tear that causes the rice kernel to break during handling or rice processing. However, information about mechanical properties using Malaysian rice variety is limited. Thus, mechanical properties are needed at various levels of moisture content and temperature are needed for accurate design of the handling and milling machinery to minimize grain damage.

1.3 Objectives of the study

The purpose of the study is to investigate the mechanics of rice grains due to milling process. This leads to the specific objectives as follows:

- To investigate the effect of drying temperature towards fracture stress of rice grain
- To study the effect of moisture content towards mechanical behavior of rice grain
- To analyse the formation of fissures during drying drying process

1.4 Scope of the study

In this research, the MR 220 rice variety was used from Sekinchan, Selangor. It was released by Malaysian Agricultural Research and Development Institute (MARDI) in 2003. MR 220 is widely cultivated in Malaysia and is the most common rice used by consumers because has suitable quality in shape and taste. This study will focus on the mechanical properties of rice grains due to drying process in order to improve the rice milling processing. The study further analyses the formation of fissure to investigate the effect of severe drying on rice grains.

1.5 Thesis Outline

- Chapter one introduces the subject of the research and the objectives of the thesis
- Chapter two will discuss the literature review from other researchers. It will discuss the methods that had been used by other researchers to study the mechanical properties of rice.
- Chapter three will explain the methodology of the research from sample preparation up to the last part of analyze the fracture or fissures from in the dried rice sample.
- Chapter four presented the results from the mechanical testing which are compression and three-point bending test on the dried milled rice samples. Along with the imaging of fracture surface of dried rice samples using SEM.
- Chapter five concludes by presents the conclusion of the study; it summarizes the finding and draws up recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Malaysian Rice

The increasing population growth in Asia has made the Asia being the biggest producer and consumer with an estimation of 70 percent increase in rice that is required to meet the demand in the future. In Malaysia, Norimah Jr (2008) showed the pattern of adult population in rice consumption where about an average of two and a half plates of rice per day. It proved that rice is the most important staple in Malaysia. In order to ensure the country's stock rice, Dasar Agromakanan Negara (DAN) has stressed that the production of local rice should be increased as 7 percent of global rice production is traded. Husain (1984) has studied the Malaysia rice market and concluded that the rice market in the future will face shortages. This is due to increasing demand and decreasing supply. Thus, the government should stop depending on imported rice and encourage the production of local rice.

Each rice growing country has a list of released rice varieties within the country. The rice varieties are based on the length of the whole kernel after rice milling. In Malaysia, the rice varieties are classified as long (>6.2 mm), medium (5.2 mm - 6.2 mm) and short (< 5.2 mm). Other grades are categorized as; broken rice, glutinous rice and parboiled rice.

The standard for classifying the local rice varieties are referred to the Food and Agricultural Organization (1956) standards. Table 2.1 shows the example of Malaysia rice varieties with their grain size. However, only two types of rice varieties which are Anak Dara and Kadaria are being produced commercially. From the table, most of the rice varieties are medium or long grains.

Table 2.1: Malaysian rice varieties

Variety	Forms of rice	Grain(mm)			Length/breadth ratio	1000 grain wt. (g)	Hectolitre wt. (kg/litre)	Hardness (kg)
		Length	Width	Thickness				
Anak Dara	Paddy	8.15	2.62	1.74	3.08	18.77	56.62	
	Brown Rice	5.93	2.22	1.53	2.67	14.81		3.66
	Milled Rice	5.69	2. 15	1.49	2.73	13.4		
Kadaria	Paddy	8.18	2.51	1.77	3.26	18.15	55.45	
	Brown Rice	5.97	2.19	1.55	2.66	14.65		3.28
	Milled Rice	5.83	2.11	1.52	2.76	13.82		
Mahsuri	Paddy	7.75	2.41	1.82	3.22	16.56	57.55	
	Brown Rice	5.46	2.12	1.56	2.58	13.08		3.65
	Milled Rice	5.38	2.04	1.53	2.64	11.81		
Mat Candu	Paddy	9.3	2.43	1.81	3.83	20.35	55.00	
	Brown Rice	6.54	2.07	1.58	3.16	16.31		3.5 1
	Milled Rice	6.41	1.97	1.52	3.25	14.72		

Pongsu Seribu	Paddy	8.33	2.48	1.78	3.35	17.8	53.25	
	Brown Rice	5.9	2.13	1.55	2.76	14.13		3.49
	Milled Rice	5.75	2.12	1.5	2.71	12.90		
Sekencang	Paddy	9.23	2.65	2.65	3.48	24.39	49.5	
	Brown Rice	6.77	2.2	I 65	2.97	19.06		3.80
	Milled Rice	6.74	2.13	1.61	3.16	17.06		
Sekembang	Paddy	8.92	2.52	1.90	3.54	21.09	50.25	
	Brown Rice	6.34	2.19	1.00	2.89	17.33		3.62
	Milled Rice	6	2. 10	1.02	2.86	15.47		
Setanjung	Paddy	8.78	2.75	2.06	3.19	27.08	54.7	4.32
	Brown Rice	6.51	2.42	1.84	2.69	21.77		
	Milled Rice	6.47	2.27	1.79	2.85	19.83		
Sri Malaysia 1	Paddy	8.27	2.90	2.02	2.85	23.44	52.30	2.78
	Brown Rice	5.92	2.56	1.71	2.31	19.04		
	Milled Rice	5.66	2.49	1.64	2.27	16.88		
Sri Malaysia 2	Paddy	9.96	2.75	2.08	3.62	29.15	59.90	3.61
	Brown Rice	7	2.30	1.81	3.16	22.81		
	Milled Rice	7.01	2.22	1.77	3.16	20.61		

In 2017/2018, there are increases in planted areas in East Malaysia even though the dry weather is expected to reduce the rice yields. Sabah and Sarawak have dominated the paddy planted areas with an increase from 3,788 kg/Ha in 2005 to 4,527 kg/Ha in 2014. Even though the western foods are gaining popularity among Malaysian consumers, domestic consumption shows stable statistic and is increased from 2.75 million in 2016/17 to 2.8 million tons in 2017/18. It shows that rice is still remained as a staple food among Malaysian. The government has provides incentives to encourage the production of local rice such as subsidized seeds, fertilizer, pesticides, and irrigation. The government also set the support for paddy rice at RM 1,200 per ton.

The cheapest local variety sold and most consumed by the Malaysian consumer is ST-15. ST-15 is a long grain of Super Tempatan with 15 percent broken. The price of ST15 is being controlled by the government and target the poor family or low-income group. The government has been subsidizing the ST15 variety to ensure the targeted group can buy at the lowest price. In urban areas, imported rice is more popular among the upper income groups but it cost double the price of ST15 variety rice. Example of imported rice is a long grain white Jasmine fragrant rice variety from Thailand, Basmati rice from Pakistan and India, glutinous rice, and sushi rice.

2.2 Paddy-rice moisture content

Moisture content is the weight of water contained in paddy-rice that expressed in percent. It is usually expressed in wet basis (w.b.) which means the total weight of the rice including the water. Moisture content is an important factor in each rice unit operations involved in rice post-harvesting whether in harvesting, drying, storage or milling. It is important to obtain accurate or optimum moisture content during rice processing especially during milling operation because milling operation will produce an edible rice which is white rice. Moisture content of paddy rice plays a crucial role during harvesting and also during rice processing. Each unit operation of rice processing has different desired or optimum moisture content and primary losses.

Too high or too low moisture content can lead to spoilage because of bacteria growth. The head rice yield will decrease, if the rice grain is too wet in storage when milling at wrong moisture content or extra drying cost if the paddy is harvested wetter than necessary. For example, the paddy rice is stored and maintained at levels of 13 percent or less. This is proved by Babamiri *et al.* (2013) where the moisture content for storage should be about 13 percent w.b. The longer the rice grain needs to be stored, the lower the moisture content should be reduced. If it is stored above the desired moisture content, it may experience the growth of molds and reduction of rice quality. The drying and storage temperature also will affect the activity of rice milling. Dhaliwal *et al.*(1991) showed that the paddy rice moisture content decrease due to low temperature and dry weather during storage and increase with the onset of the monsoon season.

In the drying process, the strength and rice milling yield depend on the drying temperature and final moisture content of the rice kernels. Babamiri and Asli-Ardeh (2013) showed that at 14 percent of moisture content had the minimum hulling waste which is the best condition for milling operation. This statement was supported by Most researchers concluded that the ideal moisture content for milling is at the range 10-13 % w.b. (depending on the variety of paddy).

Babamiri *et al.* (2013) showed that the optimum value for temperature and moisture content are determined at 43°C and 14 percent w.b. In investigation effect of moisture content on milling yields of Bluebonnet 50 long-grain rice, Pominski *et al.* (1961) proved that the paddy moisture content had a significant effect on milling yields. They concluded that for each selected sample with moisture content ranging from 10 to 14 percent, the head yields and total yields increased 3 percent and 0.7 percent for each one percent decrease in rice moisture content respectively.

Matthews and Spadaro (1976) also found out that the rice breakage during milling operations increased when the rice kernel diameter decreased. Rice breakage can be reduced by increasing the paddy moisture content from range 12 to14 percent (Dilday, 1987). Thus, this range was the optimum moisture content for paddy milling operations. According to Luh (1991), to have a high quality head rice with minimal breakage, paddy must be harvested at the optimum moisture content.

2.3 Milling operations

Milling unit operation is the most crucial step in the production of rice. It is an operation where it will convert the paddy into well-milled silky white rice, which has greater cooking quality characteristics (Roberts, 1979). The rice milling operation involved process of applying load in order to remove the husk and bran layers of rice grain will remove the husk and the bran layers of rice grain (Lu and Siebenmorgen, 1995). An efficient milling system should remove the husk (20%), bran (8-10%) and leaves 70% as white rice without damage the starchy endosperm (FAO, 1992). The number of broken kernels should be at a minimum number depending on the preference of the customers. Producing with minimum breakage during rice milling has been the primary goal for most rice industries because removal of husk and bran layers will improve the appearance, cooking quality and palatability of rice (S. Yeong and K. Ho, 2012).

The final quality of rice mainly depends on how the rice grain is milled. There are many factors that contribute to the final quality of rice production by the rice milling. These factors are the degree of milling, percentage of rice breakage, the level of impurities, the color and presence of off-type kernels such as chalkiness or damaged kernels.

Rice milling process has one step milling process, two-step milling process, and multistage milling process. For one step milling process, the white or milled rice is produced directly in one pass. Two-step processes are done with separate hulling and polishing processes, and brown rice is produced as an intermediate product. Multistage milling process is more complex because it involved a number of different processing. In modern rice milling system, many adjustments are made such as rubber roll clearance, separator bed inclination and feed rates to maximize the total milled recovery and minimize the rice breakage.

S. Yeong and K. Ho, (2012) investigate the milling conditions including moisture contents (11, 13,15, 17, and 19 percent) and kernel temperatures (0, 10, 20, 30, and 40°C) of brown rice. It shows that at 17 and 19 percent of moisture content, the ratio of broken kernels was higher during the milling process. S. Afzalinia *et al.* (2004) showed that the minimum rice breakage for tested paddy occurred at the range of 12 to 14 percent moisture content. S. Firouzi and M. Alizadeh (2011) also proved that at high paddy moisture level the percentage of broken milled rice also increased. This is due to low grain hardness at higher moisture content and high brittleness at lower moisture content. Thus, we can conclude that the rice breakage rate can be reduced at optimum moisture content which is 12 to 14 percent w.b.

Degree of milling (DOM) is a quantification of removal of the bran layer during the milling process. Several researchers have studied the effect of DOM on the head rice yield, rice food components, whiteness of rice, and cooking qualities. The degree of milling is affected by the grain characteristic in terms of hardness, size and shape, brain thickness and efficiency of milling (FAO, 2004). With increasing DOM, the milling yields and head rice yields decrease. In terms of grain size, it is found that the short grains have a greater head rice yield. However, it is insignificant to compare the milling yields between short and long grain.

The color or whiteness rice of rice plays an important factor in customer preferences. Production of a whiter color of rice is very important for higher customer acceptance and improves market value. The lightness of rice is dependant on the rate of bran removal because the color of bran is darker than polished rice (Juliano & Bechetel, 1985). P. Roy *et al.* (2008) investigated the effect of degree of milling on color intensity and lightness of rice for Japonica and Indica varieties. They concluded that the higher the DOM, the lower color intensity and the greater the lightness value.

It has been reported that consumer preferences vary from different countries to different region. Usually, majority of the rice consumer prefer more the well-milled rice where little bran is removed or no bran layers in the rice grain. For instance, in America, the consumer prefer more the semi-milled long grain or brown rice but Japanese people like well-milled sticky rice (Deshpande and Bhattacharya, 1982). In Malaysia, the preferences are more towards to well-milled long grain, slender and translucent grain although well-milled rice will lower the nutritional value since proteins, fats, vitamins and minerals are concentrated in the germ and outer layer of the starchy endosperm (A.

Husain, 1984). Mostly 10% of the brown rice weight is removed by regulating the degree of milling (DOM).

In most developing countries, Rahman *et al.* (1996) stated that the milling operation should be restricted to 7 to 8 percent for maximum recovery. The economic value of rice depends on the percent of whole milled grain production. The world paddy production is reported to be 685 million tons in 2008 (FAO, 2010). If the DOM is restricted to 0, 2, 5, 8 and 10 percent, it would produce about 541, 530, 514, 498 and 487 million tons of rice, respectively (P.Roy *et al.*, 2011). It shows that 10 percent of DOM is the best for rice milling.

There are many factors that affect the rice grain milling qualities during milling process such as type of mill, milling cylinder speed, degree of milling, temperature and duration, moisture content of the rice grain, milling procedure, and head rice separation. Table 2.2 shows the milling qualities for some Malaysia rice varieties.

Table 2.2: Milling Qualities (%) of local rice varieties

Variety	Total milling recovery	Head Rice	Husk	Bran
Anak Dara	67.2	78.2	23.1	9.7
Kadaria	67.8	79.9	22	10.2
Mahsuri	68.0	82.9	22.2	9.8
Mat Candu	66.5	69.5	23.3	11.2
Pongsu Seribu	67.2	79.4	23.3	9.5
Pulut Malaysia	66.6	83.4	21.5	11.9
Pulut Siding	66.2	70.4	23.0	10.8
Sekencang	68.3	73.0	22.1	9.6
Sekembang	70.5	78.8	20.1	9.4
Setanjung	70.4	76.3	20.8	8.8
Sri Malaysia 1	64.5	54.4	23.9	11.6
Sri Malaysia 2	67.5	64.5	22.4	10.1

2.4 Polishing method

There are several methods to mill the rice grain. In compact rice mill machine, two-step milling process is carried out by removing the husk and the bran separately. This method has separate hulling and polishing processes. Polishing process is one of the steps in rice milling where the milled rice will go through polishers that remove bran adhering to the surface of milled rice and improved its translucency or whiteness. Among all of the unit operation involved in milling process, bran removal is a major and critical step of operation.

The polishing process which conducted by using rubber rollers with a steel friction whitener or Engleberg-type is no longer acceptable in the rice milling sector because they lead to low milling recovery and high grain breakage (IRRI, 2003). Nowadays, most rice industries using rubber roll huller with combinations of abrasive and friction type milling machines to remove the bran layer. For friction type milling machine, the grains were rubbed in milling chamber in order to remove the bran layer. In abrasive type, the brown rice grains were abrasive by abrasion stone to separate the kernels of brown rice from unhulled paddies.

Milling recovery and head rice yield will be improved if dehusker is used before milling process. Types of milling methods and operation method have a significant effect on the rice breakage during milling process (FAO, 2010). S. Afzalina *et al.* (2004) studied the effect different milling method and different level moisture content on the rice breakage and rice quality. The methods that they used are; (i) three abrasive type whiteners in series and a rubber brush polisher, (ii) three abrasive type whiteners in series and a friction type whitener as a polisher, and (iii) two friction type whiteners in series without polisher and four abrasive type whiteners in series without polisher.

They concluded that method using three abrasive type whiteners in series with a friction whitener as polisher had the minimum rice breakage and best rice quality while friction type whitener produce the highest amount of rice breakage. They also reported that at 12 to 14 percent moisture content is the optimum moisture content during milling process. Having at least two stage in the whitening process with separate polisher will ensure higher milling rate and head rice recovery. The economic evaluation also showed that this method has lowest milling cost.

Araullo *et al*. (1976) also investigate the effect on the rice breakage and concluded that using combination of three abrasive whiteners in series and one friction whitener will minimize the rice breakage rate. According to S. Firouzi and M. Alizadeh (2011), they test the long paddy variety named *Hashemi* with three types of polisher which are abrasive type, blade-type and frictional-type bladeless with different level of moisture content from range of 8 to 13 percent w.b. From the result, the moisture level and type of polishing method has significant effect on rice breakage.

Blade-type has the highest amount of rice breakage compare to abrasive type. This is because of pressure exerted by the blade and cause more pressure on milling chamber and more friction between brown rice and the paddies. While in abrasive type, less pressure is required because the rice grains are polished through rubbing on roll grinder stone. Thus, the amount of rice breakage is reduced because less friction is produced. They also reported that at lowest moisture content at 8-9% w.b., the rice breakage is obtained at minimum percentage because high brittleness of the rice grain at low moisture content compare to high moisture level that have low hardness.

In Japanese rice industry, new innovations have been introduced based on the desired degree of milling and whiteness of milled rice (Furugori, 1985; Van Ruiten, 1985). For example, germ rice milling method was introduced in 1976 where it uses an abrasive roller under little pressure and leaves the germ intact with the rice grains for more than 80 percent. It is well received among Japanese consumer because it is rich with in thiamine, riboflavin, tocopherol, calcium, and linoleic acid.

2.5 Grain Quality

It is important to obtain the criteria of rice quality that will reflect with the consumers because consumers will pay in the retail market. The demands for greater quality are increased since the rice market is becoming more competitive. Most consumers in all countries prefer higher head rice yield and high value of translucent grain. In Malaysia, imported rice becomes more popular among Malaysia consumer than that of locally produced rice. Moisture content is the most important criteria that will indicate the grain quality. There are significant differences in grain quality within a rice varieties. In Asia, physico-chemical properties relatively constant. The rice milling process mainly will determine the nutritional value of rice grain.

Physical properties such as length, width, translucency, degree of milling, color and age of milled rice are the quality parameters in determine the grain quality. A. Husain (1984) had been studied the important quality parameter in evaluating the quality of the Malaysian rice varieties. For appearance, the best quality rice should have bright and highly translucent milled rice and also free from chalky spots. The milled rice is characterized as chalky if part of the milled rice kernel is denser rather than translucent. Rice manufacturer usually places the limitation amount of chalkiness because it will contributes rice breakage during milling. This is because chalky grains are more brittle and easy to break during rice milling.

Degree of milling has been the major problem in determining the quality of milled rice (A. Husain, 1984). The milling degree can be categorized into under-milled, lightly milled and well milled. Under-milled is the lowest quality of milled rice because it is under polished rice or there is still bran remaining left in the rice grain. Majority of the consumer preferred well-milled rice where the bran in completely removed and has better appearance even though it lowering the nutritional value.

The quality of rice in the international market is categorized into high quality long grain, medium quality long grain, short grain, parboiled rice, fragrant rice or glutinous rice (Efferson, 1985). High quality long grain is sold mostly in Europe and Near East, medium quality long-grain rice in the deficit countries of Asia, short-grain product in various special-demand areas, high-quality parboiled rice in the Near East and Africa and the lower-quality parboiled rice in special markets in Asia and Africa.

2.6 Determination of mechanical properties

To obtain the minimum rice breakage and to maximize the head rice yield during milling process is very important for every rice manufacturer. It has become one of the biggest problems due to the large amount of grain losses during post-harvest processing. Basically, the broken grains during milling process are used as feeds for livestocks instead of for human consumption. To predict the cracking of rice grains during drying and subsequent process, it is necessary to know the mechanical properties and Young 's modulus of the rice grains for the improvement of existing milling machines and development of new types of machines.

The breakage of rice grains can be caused by the stress related to shrinkage during drying process due to tensile failure in the center of the grain. In shrinking system, moisture content and temperature are the important factor to determine the volume of material. If the stress exceeds the failure strength of the rice grains, this will lead to rice breakage. Thus, the rice quality will loss and reduce the economic value. Siebenmorgen (1994) also reported that the economic value of the dried product is strongly dependent on the percentage of unbroken kernels, which are roughly worth twice as much as broken kernels.

Kunze and Choudhury (1972) also explained that the grain breakage is due to tensile failure. They explained that this is due to compressive stress during equilibration of moisture distribution. The surface cells of rice grain will expand because the volume of the cells in the inner parts of the rice grain remains the same or decrease and this will implies a tensile stress in the center due to force balance.

It is important to study the tensile strength of the rice grains to be able to predict the rice breakage. Kunze and Choudhury (1972) studied the tensile strength by applying uniaxial tension test with different moisture content ranging from 6 to 19.5 percent d.b. They reported that the tensile strength values were lower at higher moisture content. The deformation rate also has an influence on the mechanical properties of rice grains (Chattopadyay & Hamann, 1994). There are several methods to study the mechanical properties of the rice grains besides the uniaxial tension test. Other method that have been used to determine the tensile stress is diametral compression test.

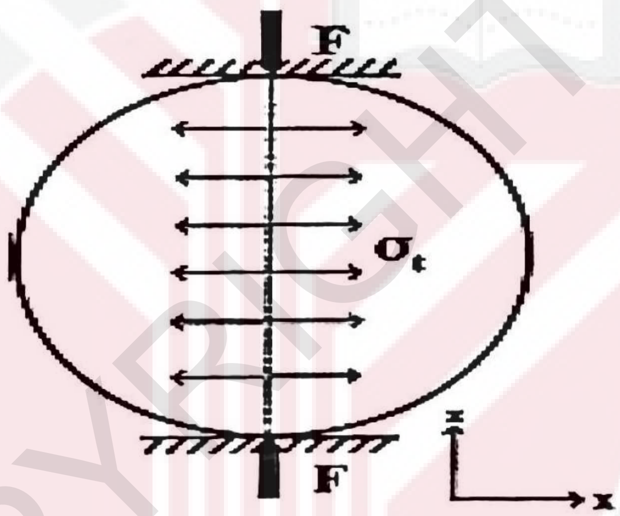


Figure 2.1: Diametral Compression

G. Kamst, J. Vasseur, C. Bonazzi et al. (1999) conduct the experiment by using diametral compression to investigate crack of the rice grain. The breakage will occur at the maximum tensile stress. It shows that grain is dividing into two equal half cylinder from the photograph of cross section of a rice grain (Figure 2.2). They also prove that the fracture is caused by the tensile stress only. They observed that the fracture is not caused by compression or shear stress and stated that both tensile strength and Young's modulus decrease with increasing moisture content. The first maximum of stress-strain curve is defined as the failure stress.

Woueters and Baerdemacker (1987) investigate the mechanical properties by using quasi-static compressive method on the rice kernels. Six different levels of moisture content were tested ranging from 5 percent to 30 percent (d.b.). The results show that at the critical range of moisture content between 12 percent and 18 percent d.b. , the mechanical properties change drastically. This is because there is an increase in free water content in the kernel which makes it more plastic behavior.

Prasad and Gupta (1973) were performed lateral compression at different deformation rates ranging from 0.5 mm min^{-1} to 10 mm min^{-1} at different level of moisture contents of 12%, 15, 18, 21 and 24 percent d.b. They stated that the rice was behaving more fluid-like at higher moisture content. This is because they observed a drastic change in yield point values of 12 percent and 18 percent d.b. than in the range 18 percent to 24 percent d.b. moisture content.

Bamrungwong *et al.* (1987) also investigate the difference between long grain brown rice and milled rice by determining the compressive properties under lateral compression test. They showed that at higher moisture content, the breaking load of the rice kernels will be lower. The milled rice had lower breaking load compare to brown rice. The breaking energy will be lower as moisture content increase. In addition, the brown rice had a higher breaking energy than milled rice. In terms of modulus elasticity, the higher the moisture content the lower the modulus of elasticity. However, milled rice had a higher elastic modulus than the brown rice.

They also discovered the breaking point of three-point bending is similar to contact-point compression test. It showed that the rice kernels had elastic behavior and brittle behavior at moisture content less than 18.8 percent d.b. They also discovered lower bending breaking force needed at high moisture content which is 15-18 N for milled long grain. Thus, it cleared that high moisture content was relatively weaker and easily broken during milling process. Moisture content also gives effect on the breaking deflection during bending test. The higher the moisture content, the breaking deflection will slightly decrease.

Lee (1972) and Yamaguchi *et al.* (1981) also show that higher moisture content rice kernels require low breaking force under compression and bending test. Sadeghi *et al.*(n.d.) measured the mechanical properties of rice kernels for different rice varieties and different moisture content by performed compression and three-point bending test. Rice variety and moisture content has significant effect on mechanical properties ($P < 0.01$). Siebenmorgen and Qin (2005) stated that one of the factors that affect breaking force of rice kernels is the presence of fissures. Fissure is a large internal fracture where it usually found to be perpendicular to the long axis of the rice kernel (Sharma & Kunze, 1982).

2.7 Effect of drying conditions on rice kernels

Dryers such as colum or deep-bed heated air dryers can provide moisture-adsorbing environment during drying process of rice grains. As heated-air enters the bed of field-moisture rice, it will gain moisture from the wet rice grains until drying front reaches them and become humid and warm. Drying front is the area of heat and mass exchange in the grain bed. Thus, the fissure develop because they are adsorbing the moisture, and not because the grains are drying. Mannapperuma (1975) discussed in his research that the grains contracts when it dries.

The drying process has a significant effect on rice kernel fissures when it exposed to high temperature or humid conditions and dried below critical moisture content. The drying process can induce fissure in the rice kernel and typically cause kernel breakage during milling process. Percentage of fissured kernel increased rapidly in the first 4 hours after drying and there was no further increase in fissure above 48 hours (Li *et al.*,1999). Arora *et al.* (1973) suggests that it was better to maintain the drying air temperature below a temperature of 53°C in order to reduce kernel thermal stress.

Cnossen and Siebenmorgen (2000) also suggested the formation of fissure during drying process because of hygroscopic behavior inside the rice kernels. They also stated that when use drying air temperature at 60°C, 5 to 6 percentage points of MC can be removed in a single drying pass. Drying air temperature increase, will resulted in progressive increases in fissured kernel percentage (Siebenmorgen *et al.*, 2005). Slow drying air temperature will minimize fissure formation. Hypothesis has been made by Cnosen and Siebenmorgen (2000) indicated that fissures will occur if a sufficient internal kernel MC gradient is present as a significant portion of the surface of the kernel transitions from a rubbery to glass state. The center portion in the rice kernel remains in the rubbery state. Increasing drying treatment severity will increase in numbers of rice kernels and subsequently low breaking force. As drying temperature increased, the fissured kernel percentage generally increased at given post-drying durations across the rice kernels.

Researchers found that the fissure was developed caused by stress shrinkage in the kernel because of uneven distribution of the moisture rice kernel during moisture adsorption or desorption, particularly during high temperature drying because of rapid decreasing of moisture in rough rice. Effect of fissure is significant on hardness, gumminess and chewiness. The rice fissure caused the taste quality of cooked rice decrease through the texture attribute including hardness, springiness, gumminess, chewiness and resilience (Zheng *et al.*, 2009)

Most critical moisture content is in the range of 14 to 18 percent moisture content. Below the critical moisture it is brittle and mechanical stress above the strength limit of the kernel can cause it to break and form a fissure. During drying, the outside of dry rice kernels gains moisture when exposed to humid conditions and expands against the inside. Fissuring also occur in heated air drying and these limit the amount of moisture removed during each pass through a dryer.

During drying, moisture content is removed from the kernel mainly near the region around the germ. This area has a low moisture and the area farther from the germ have high moisture. Continuous moisture loss rates less than 1.5 percent per hour internal stress do not reach a level that cause fissuring. The dry grain can be cracked by the high humidity caused by the higher moisture rice (Anon, 2003).

Cnossen and Siebenmorgen (2000) discussed that the problem in rice fissuring is serious when heated-air at higher temperature such as 60°C. When the strength of rice kernels were exceeded by the internal stress, fissures are developed due to moisture content gradient induced during drying (Jia *et al.*, 2002; Sarker and Kunze, 1996; Yang *et al.*, 2002). At lower moisture content, the apparent modulus of elasticity, bending strength and fracture energy of the brown rice kernels increased when dried at 60°C using thin-layer dryer (Zhang *et al.*, 2005). The sound of brown rice kernels becomes stronger and tougher as result from three-point bending test as drying time increased. They suggested that drying will initiates fissure as it provides desorptive environment.

2.8 Detection of fissure in rice kernel

One of the most important tasks in rice grain quality is stress fissure detection. Detection of stress cracks can be examined manually by candling the kernels with a fiber optic (Yubin Lan and Kunze, 1996). To observe the stress cracks caused by combination of thermal, moisture and mechanical stress, most of the examination methods involve a candling where light is transmitted (Stermer and Kunze, 1994). However, this method gives a lot of disadvantages because this procedure is slow, labor intensive and difficult in situations where the inspection task is repeated in routine basis. Furthermore, detection of fissure is complicated do to rice kernels are irregular in shape, composite and anisotropic, non-uniform and non-homogenous.

Thus, most researchers use machine vision for fissure detection because detection method is more easy, objective and more consistent. Gunasekaran *et al.*(1985) developed a computer vision system to analyze stress crack in a corn kernel image. Machine vision also had been used to detect fissure or cracks in eggs (Patel *et al.*, 1998). They found that the best contrast between the cracks and the rest of the surface of the egg is produced using a Speed-king lamp. The image analysed performed well and determine whether or not an egg was cracked 95.6 percent correctly at the time samples tested. However, machine vision procedure has not been investigated to detect stress cracks in rice grains. The most significant loss to rice manufacturers is broken rice grains.

In one of a study, a machine system was used which consisted of a CCD (Charge Coupled Device) black/white camera, an image frame grabber, and a computer to obtain images of fissured rice a grain (Y. Lan *et al.*, 2002). Procedures of image processing program (Image-Pro Plus) were developed to detect fissures in rice grains. They analyze the images of the fissure pattern difference between long and medium grain rice. The computer vision was able to reveal 94 percent of the entire fissure in medium rice samples and 100 percent in long rice samples.

Dang and Copeland (2004) have studied detection of fracture surface of rice grains using environmental scanning electron microscopy (ESEM) which the specimens can be analyzed at high resolution with minimal preparation. ESEM is an upgraded version of scanning electron microscopy (SEM) where it can used for studying dynamic changes in biological tissues and synthetic polymers. From ESEM, they discovered the area of weakness that makes grains more susceptible cracking is the interface between the cell wall and the cytoplasm inside endosperm cell. Conventional SEM provides valuable information on surface topography. However, its disadvantage is lies in the need of complicated sample preparation and observation of specimens under vacuum.

Besides that, there is another method had been used to analyze the fissures in dried rice kernels which is using X-Rays. Menezes *et al.* (2012) had proved that this method can identify the fissures in the rice kernels. They dried the rice kernels at temperature of 32, 38, 44 and 50°C. They found that higher temperature will increased the percentage of fissures

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Materials

The paddy used in this study were freshly harvested from Sekinchan. The paddy variety used is MR 220 (Figure 3.1). Malaysia Indica rice variety, MR 220 had been released by Malaysian Agricultural Research and Development Institute (MARDI) on 10 October 2003 at FELCRA Seberang Perak (Alias *et al.,* 2005). It has the same breed as MR 219, which had been gone through the same selection process except at the resultant rating stage. The MR 220 breeding process is produced by a cross between MR 151 and MR 13. MR 220 also known as Padi Mas among local farmers, has shown some advantanges. It took about 12 years to evaluate the best features and performance of MR 220 for being recommended to the local farmers. According to Alias *et al.*(2005).Most of their charasteristics such as maturation period, plant height, grain shape, milling and cooked rice quality are similar to MR 219 because it is a sister line to MR 219 except MR 220 has slightly more stable performance under varied environments.

The paddy samples, and then were dried in laboratory oven. The initial moisture content of the grains determined using digital moisture meter (model GMK-303) was 17 percent.

Figure 3.1: MR 220 rice variety

3.2 Methodology

3.2.1 Dehusking, Milling and Grading

The paddy samples were undergone dehusking and milling operation. The paddy was dehusked using a SATAKE paddy dehusker (Figure 3.2). The purpose of dehusking process is to separate rice husk from brown rice. Then, trial and error method was during milling using rice polisher SATAKE (Figure 3.3) to obtain the desired milling degree. The milling degree can be increased with increase the duration of milling process.

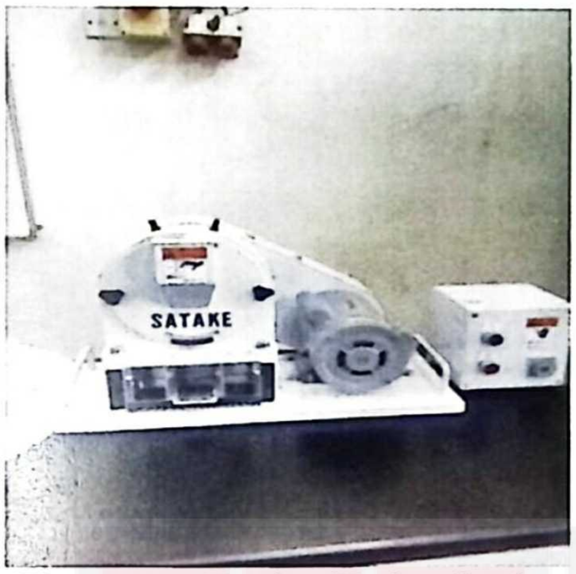


Figure 3.2: Testing Husker Satake

Figure 3.3:Rice Polisher Satake

Milling Meter MM1D (Figure 3.4) was used to test the whiteness and transparency values, which are the indicators of the rice appearance. It is also can display milling degree which indicates the percentage of bran removal. This equipment is useful to avoid over-milling or under-milling during milling process. The milled rice samples are placed into the sample case and insert the case into the milling meter. All measurement is calculated automatically. Each sample were repeated three times to obtain on accurate value.

Figure 3.4:Milling Meter MM1D

After acquired desired milling degree, the paddy grain were undergone grading operation using SATAKE rice grading (Figure 3.5). The rice grains were graded according to the length. The degree of separation can be selected from 0 to 100^0.

Figure 3.5:Satake Rice Grader TWL05C-T

The rice samples were dried in inline paddy dryer at desired temperature as shown in Figure 3.6. Approximately 20 g of rice samples were spread in sieve tray and the initial moisture content of the rice was measured using Moisture Analyzer. The tray consists of rice samples was put inside the drying chamber. The control unit air condition was set for each drying run consisted of setting at one of six temperature settings which are 40°C, 50°C, 60°C, 70°C, 80°C and 90°C for 5 hours. As the drying process commenced, a small amount of the rice samples were taken out from the drying chamber for every one hour. Shortly after that, the sample moisture content were measured using Moisture Analyzer. Immediately after drying, all 6 samples were placed into sealed bags. The air settings conditions will cause moisture desorption from kernels (Cnossen and Siebenmorgen, 2000).

Figure 3.6:Inline Paddy Dryer

3.2.3 Compression test

Diametral compression test is conducted to study the mechanical properties and rheological properties of rice such as elastic and plastic characteristics. It is suitable to investigate the fracture limits of a food material. In this test the rice kernel is compressed at horizontal position between two plates. This method is proved to be the best method to determine mechanical properties according to Kamst *et al.* (1999).

In this study, compression test was conducted using texture analyzer (Figure 3.7). Basically, the rice sample is placed on a flat surface and the upper compression platen will be lowered and compressed the sample. Compression force was applied to the middle part of the rice kernel with the circular indenter at a speed of 10mm/ sec. 10 N force was applied to the rice kernel. The compression unit assembly of the universal testing machine consisted of a compression indenter, a metal base, a crosshead and a compression load cell.

The compression indenter and the metal base were parallel flat plates type. The rice kernel was arranged with lateral broadsides laying on the metal base and facing the flat face of the compression indenter. The compression test was performed with fully automatic equipment. During the operation, force-deformation curve simultaneously plotted on the screen was observed. Three replication were conducted for each rice samples.

Figure 3.7: Texture Analyzer

3.2.4 Three point bending test

To determine individual kernel breaking force, a three-point bending test was conducted using texture analyzer (Figure 3.7). The specimen was placed on the bending set on the center balance as shown in Figure 3.8. The bending span of the contact is 4 mm. Bending force was applied to the middle part of the rice kernel with the circular indenter at a speed of 10mm/ sec. 10 N force was applied to the rice kernel. Simultaneous with this action, observation was needed to ensure the kernel did not lose its balance. Software provided with texture analyzer was used to record the force-deformation curve for each rice kernel, from which the force at failure was determined.

Bending testing is conducted by bending the material rather than pushing or pulling to determine the relationship between bending stress and deflection. Three replication were conducted for each rice samples.

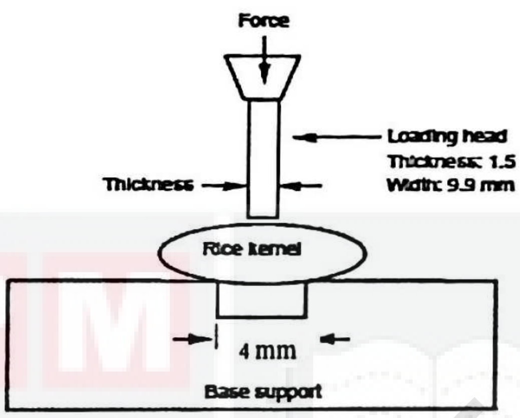


Figure 3.8: Schematic of the three-point bending test equipment

3.2.5 Imagings of the fracture surface structure of rice grains

After carrying out compression test and point bending point, the fracture surface structure analysis for each rice samples were done using Dino-lite digital microscope (Figure 3.9) for 200x magnification and Scanning Electron Microscopy (JSM- 6400, Japan) (Figure 3.10) at different magnification between 100x and 2000x. SEM is an electron microscope that photograph the surface of the sample by scanning it with high-energy beam of electrons.

SEM can reveal the details about less than 1 to 5 mm in size by producing very high-resolution images of a sample. SEM is beneficial for understanding the surface structure of the specimen due to very narrow electron beam. Thus, SEM micrographs have a large depth of field yielding a characteristic three dimensional appearance. The electron charging effects in a Polaron SC515 sputter coater are eliminated by attach the test specimen to an aluminium mount with double-sided sticky tape and sputtered with gold. The outer surface on the lateral side of the kernel was observed. The samples were examined and photographed.

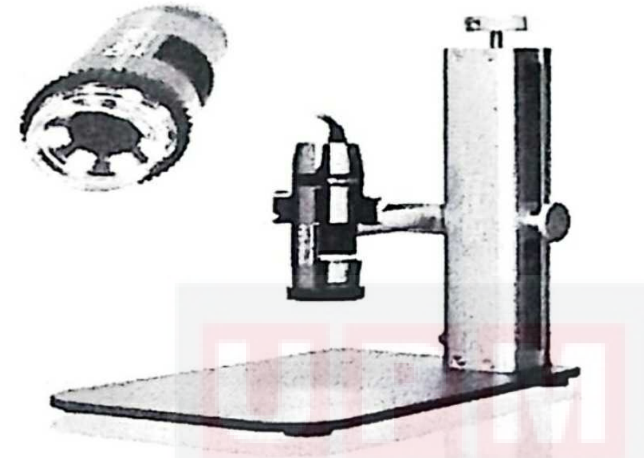


Figure 3.9: Dino-Lite Digital Microscope

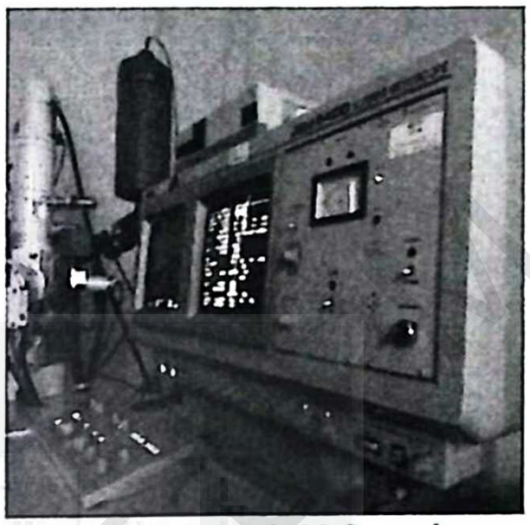


Figure 3.10:JSM 6400 Scanning Microscope

CHAPTER 4

RESULT AND DISCUSSION

4.1 Relationship between Moisture Content and Drying Time

Figure 4.1 shows the relationship between moisture content of the rice kernels and drying time for 1 hour to 5 hour. In the figure, the moisture content decreased with increasing drying time. For first 1 hour, the moisture content show rapid decreasing and followed by slightly decreasing until it reached 5 hours of drying for each temperature. The highest range of moisture content is (14.4% d.b. - 10.4% d.b.) at 90°C and the lowest range of moisture content is (14.7% d.b.-12.6%) d.b. at 40°C.

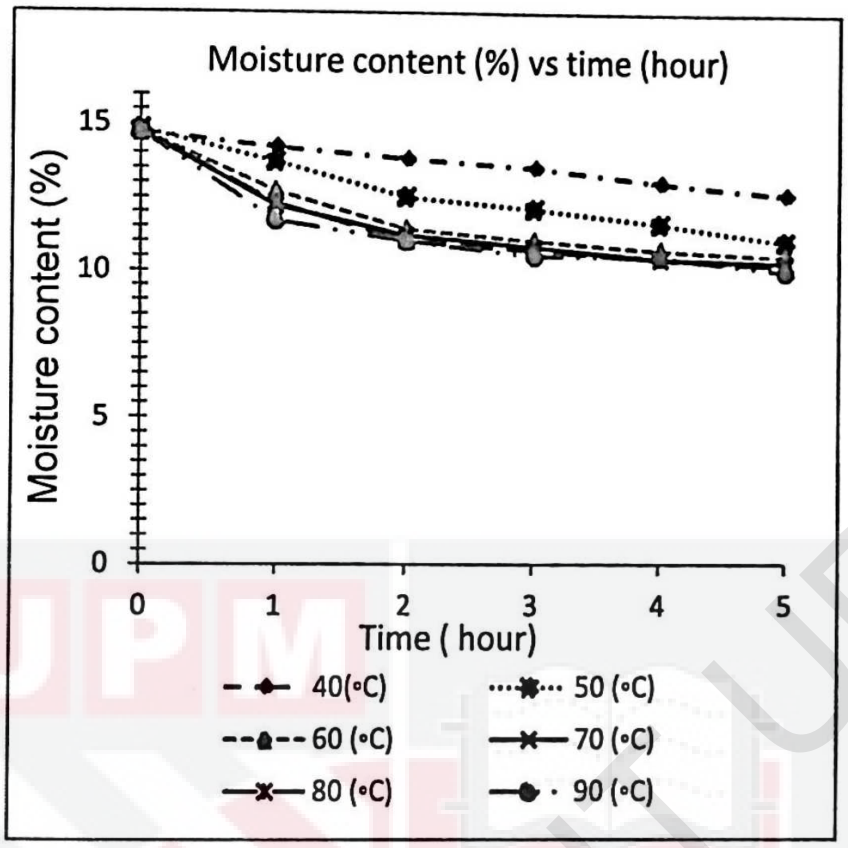


Figure 4.1: Relationship between moisture content and drying time

In Figure 4.2, the graph shows the rate of moisture loss for each temperature. In the figure, the rate of moisture loss shows rapid increasing from 40°C to 50°C and followed by gradually increasing to 90°C. The highest rate of moisture loss is at 90°C (0.94%d.b./ hour) and the lowest rate of moisture loss is at 40°C (0.42%d.b./ hour). Rate of moisture loss is amount of moisture is removed within 5 hours of drying at specified temperature. This shows rice has hygroscopic behavior which it is easily desorb moisture when it is moving from one temperature to another temperature until it reaches equilibrium condition especially when there is greater temperature difference between drying air and rice kernel (Cnossen and Siebenmorgen, 2000). Desorption is a process of release water in the form of vapor.

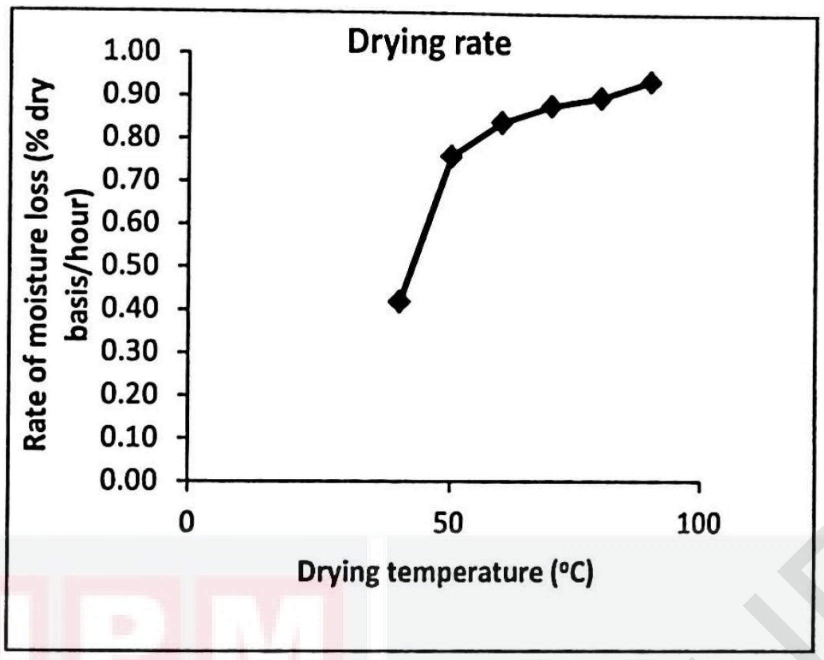


Figure 4.2:Relationship between drying temperature and rate of moisture loss

4.2 Relationship betweeen Force-Deformation

4.2.1 Relationship between compressive deformation-load

Figures 4.3 show the typical force-displacement curve from the compression test for each temperature from 40°C to 90°C at 1, 3 and 5 hours of drying. The curve initially inhibited increasing non-linear followed by a linear increase until reach a point where it abruptly dropped down. From the observation, the initial non-linear of the line was probably due to the initial contact load applied at a point on the convex surface of the rice kernel. The deformation of rice kernel began when the flat surface of the compression indenter touched down the convex surface of the rice kernel.

The contact area changed from a point to an electrical area when uniform load was continuously applied. The initial non-linear force-displacement curve can be explained from this change. Then, applied load is increased resulted in proportionate increase of deformation which explains the behavior of linear curve. The breaking point is showed at the sudden drop at the end of the curve which indicated the behaviour of the rice kernel as a brittle material. Furthermore, there was no yield point and no occurrence of plastic deformation from all the figures. Thus, the breaking strength and ultimate strength are the same.

Similar typical force-displacement curve is obtained from the experiments by Bamrungwong *et al.* (1987). Results from their study showed a similarity to the force-displacement curve during initial compression. Lee (1972) and Yamaguchi (1981) also obtained the same characteristic of force-displacement curve during initial compression but exhibited a plastic deformation curve before rupture. Lee (1972) had cut off the two ends of rice kernel and conducts the compression test it longitudinally while Yamaguchi (1981) cut the cylindrical shape out of the rice kernel and subjected to its length, width and thickness to uniaxial longitudinal compression.

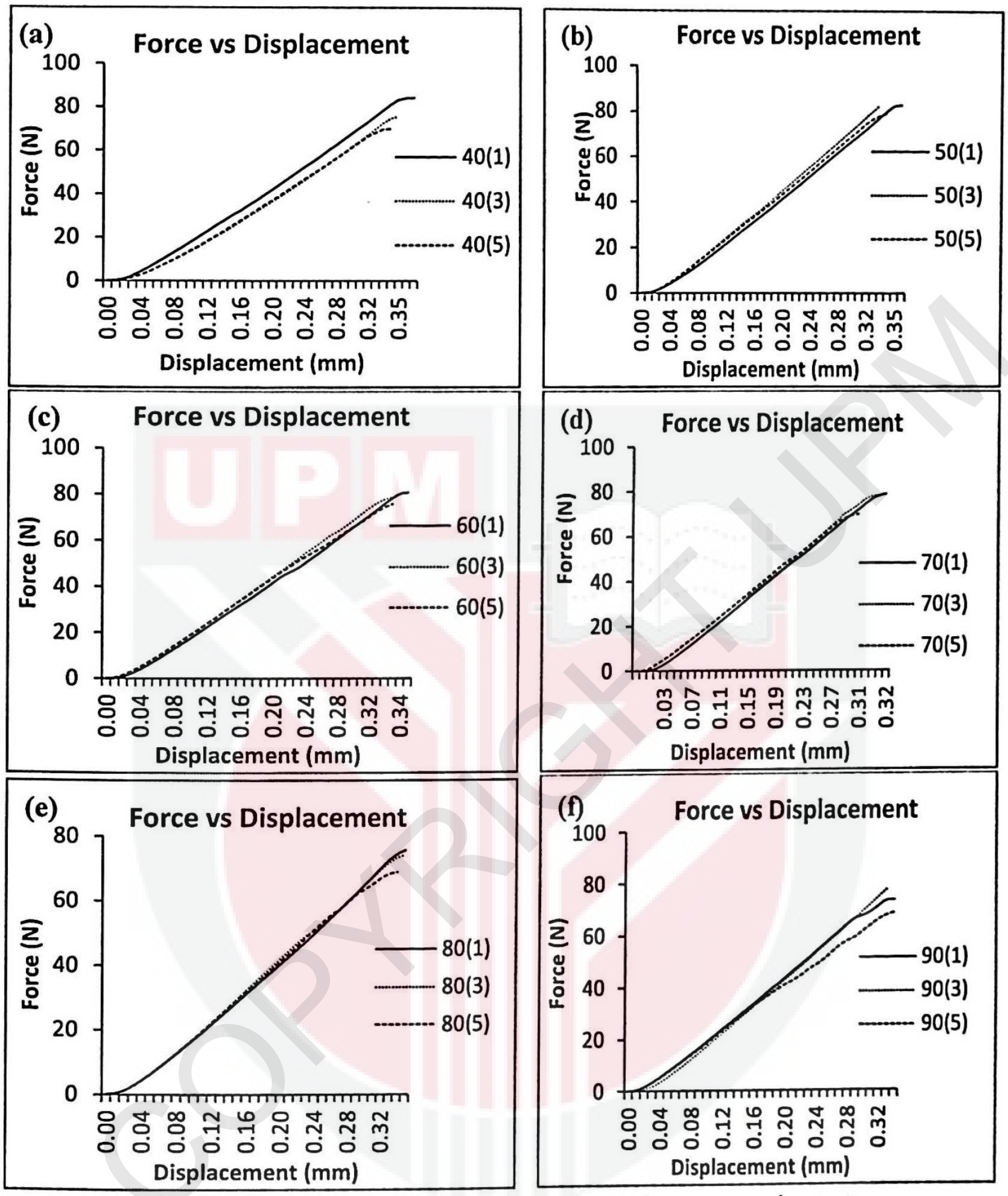


Figure 4.3: Force-displacement curve under compression test
(a) 40°C (b) 50°C (c) 60°C (d) 70°C (e) 80°C (f) 90°C

4.2.2 Relationship between bending load and displacement

Figures 4.4 show the typical graph of force-displacement curve under three-point bending testing. The figures indicate the curve for each temperature obtained exhibited a gradual non-linear increase followed by linear increase until it reached breaking point. It was observed that the curve is similar to the curve obtain in compression test. However, the curve showed a lower slope and lower breaking forces as compared to the curve in the compression test. Same explanation as in compression test for curve behavior because it is assumed the initial non-linearity of the curve is similar as in compression test. It was due to the resulting effect attributed to the contact area of convex surface of the rice kernel. The linear of the curve showed the elastic behavior of the rice kernels. At the end of the linear curve is the breaking point where it could be explained as the sudden breakage or separation of the rice kernel during bending test. There was no yield point or plastic deformation in the bending test which similar in compression test. From the pattern curve, the rice kernels exhibited a behavior of the brittle materials.

It can be seen that, increasing the drying time will decrease the breaking force to crack the individual rice kernel. Each temperature of 40°C, 50°C, 60°C, 70°C, 80°C and 90°C show that 5 hours of drying will have high breaking forces which are 21 N, 28 N, 15 N, 9 N, 7 N and 5 N, respectively. At 40°C and 90°C of drying temperature, it shows significant difference in the value of fracture stress. At the lowest temperature which is 40°C, fracture stresses needed to crack the milled rice are 34 N, 27 N, and 21 N for 1, 3 and 5 hours of drying, respectively. From this test, the milled rice kernels were relatively weaker under bending to that of compression with same moisture content.

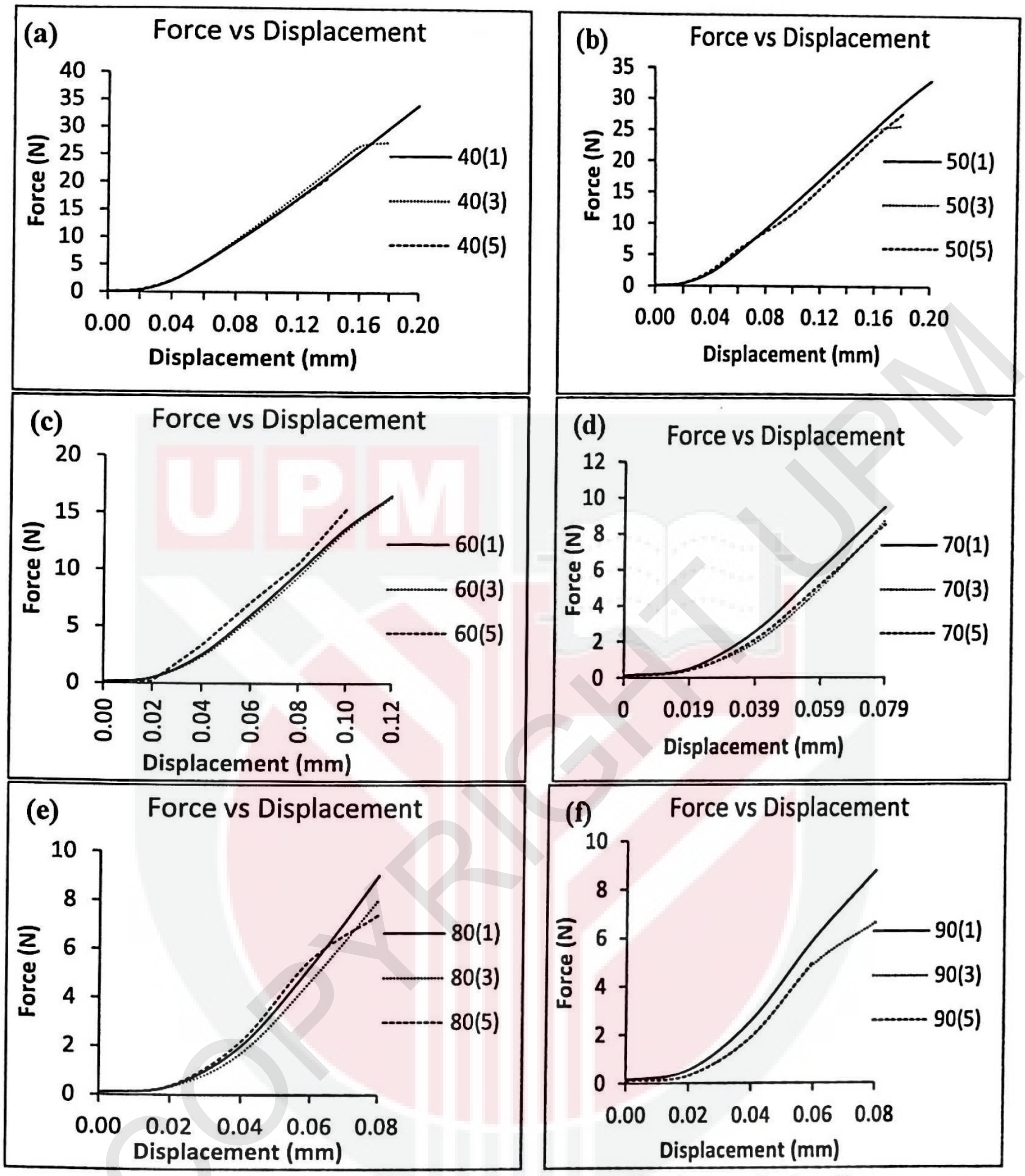


Figure 4.4:Force-displacement curve under three point bending
(a) 40°C (b) 50°C (c) 60°C (d) 70°C (e) 80°C (f) 90°C

4.3 Effect of Drying Temperature on Breaking Force

4.3.1 Compression test

Drying and compression test were carried out to investigate the influence of drying air temperature on breaking force of rice kernel. Figure 4.5 shows the relationship between breaking forces of sample dried at 40°C, 50°C, 60°C, 70°C, 80°C, and 90°C correspond from initial moisture content of 15.1%, 14.8%, 14.7%, 14.7%, 14.7% and 14.7% respectively for first drying hour which is the optimum moisture content for milling process (Babamiri and Asli-Ardeh, 2013). The moisture content after drying are varied depending drying air temperature from 14.2% to 12.6% (40°C), 13.7% to 11.0% (50°C), 12.2% to 10.3% (60°C), 12.3% to 10.4% (70°C) and 11.7% to 10.4% (80°C). The curve obtained exhibit non-linear gradually decrease when it is subjected to compression tests.

The mean values of fracture stress for compression test are depending on the drying temperature. Under this condition, the breaking forces for 40°C, 50°C, 60°C, 70°C, 80°C and 90°C are 84 N, 83 N, 81 N, 79 N, 76 N, and 74 N, respectively. In the Figure 4.5, the breaking force decreased as the drying temperature increase. At 40°C, the rice kernel exhibited higher breaking force compare to high temperature of 90°C. This may due to little fissure developed in the rice kernel at 40°C compare to 90°C. However, the breaking force for all temperature showed no significant difference compare to bending test.

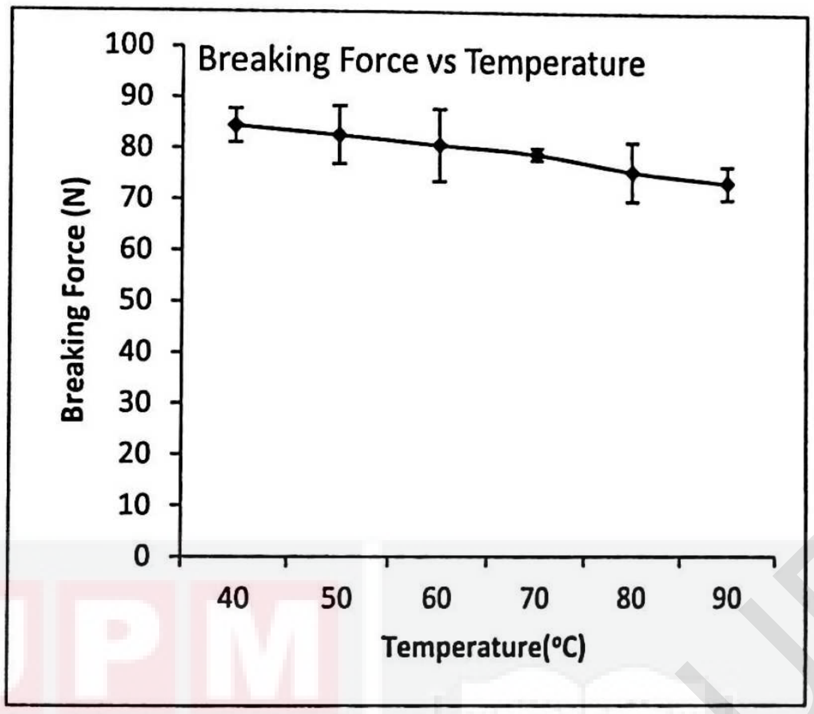


Figure 4.5: Relationship between breaking force and drying temperature on compression

4.3.2 Three - point bending test

Drying and three-point bending experiments were carried out to investigate the influence of drying air temperature on breaking force of rice kernel. The condition of the samples used is same as in compression test. Figure 4.6 indicates, the curve obtained exhibit non-linear gradually decrease and followed by linearity decrease when it is subjected to three-point bending tests. The mean values of breaking forces for three-point bending test are depending on the drying temperature. Under this condition, the fracture stress of 40°C, 50°C, 60°C, 70°C, 80°C and 90°C are 34.11 N, 33.12 N, 16.49 N, 9.52 N, 9.04 N and 8.78 N respectively for first hour of drying. The results shows the same hypothesis as in compression test which the higher the temperature, the lower breaking force needed to crack the rice kernel. Compare to compression test, drying temperature had a significant effect the breaking force on bending test.

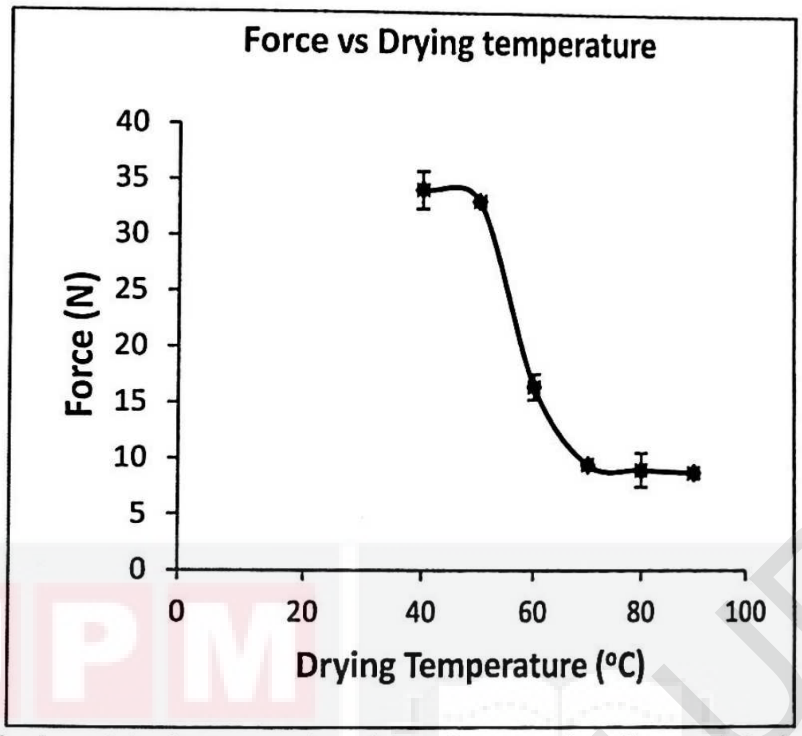


Figure 4.6:Relationship between breaking force on bending and drying temperature

At low drying temperature of 40°C and 50°C, high breaking force needed to break the rice kernels which are 33 N and 34 N, respectively. It can be observed from the curve that it starts decrease slowly at the initial part of the curve,. This may due to no fissure or small fissure is developed in the rice kernels and made it hard to break. The curve starts to decrease sharply as the drying air temperature increase from 60°C to 90°C. From this result, increasing drying temperature severity will produced low breaking force. This is due to extreme moisture desorption environment that caused extensive fissuring in rice kernels. According to Arora *et al.* (1973), it is better to maintain drying air temperature below 53°C to minimize thermal stress.

Siebenmorgen *et al.* (2005) also studied the influence of drying temperature at 40°C, 45°C, 50°C, 55°C, and 60°C. The samples were dried at initial MC approximately 21%. After the samples dried at respective drying temperature, the samples were placed in sealed plastic bag. They discovered that increasing drying air temperature severity will produced high breaking force. Their explaination is based on hypothesis made by

Cnossen and Siebenmorgen (2000) indicates that rice kernel needs sufficient internal MC gradient to develop fissures in rice kernel. After drying, the gradients cause moisture to diffuse from the center part to the surface. Thus, it causes the moisture gradient to decrease, and subsequently the surface of the rice grain start to gain moisture and expand. The milled rice interior will lose moisture and contract, producing fissure after several hours of drying. Fissured rice will break during milling process. The dryer has provides moisture-deadsorbing environments that produce fissures in low moisture content of rice grains.

4.4 Effect of Drying Temperature on Displacement

4.4.1 Compression Test

Figure 4.7 shows the relationship between drying temperature and breaking displacement under compression of MR 220 variety with temperature starting from 40° C to 90°C. It showed that higher drying temperature resulted in slightly decreased breaking displacement. The total displacement needed for the temperature at 40°C, 50°C, 60°C, 70°C, 80°C, and 90°C were 0.349 mm, 0.340 mm, 0.335 mm, 0.324 mm, 0.319 mm, and 0.316 mm, respectively. It can be seen there is no significant difference of breaking displacement between the temperature because the value breaking displacement was almost similar.

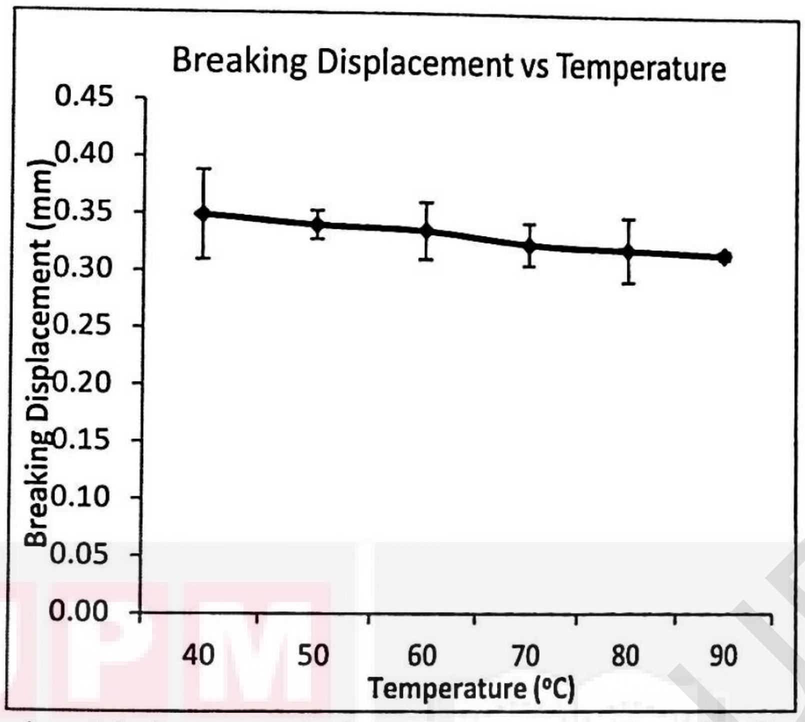


Figure 4.7: Relationship between drying temperature and breaking displacement under compression

4.4.2 Three-point bending

In Figure 4.8, the effect of drying temperature on the breaking displacement of MR 220 under three-point bending was shown. Total displacement needed to break the rice kernel was defined as breaking displacement. The figure shows the mean value of breaking displacement for drying time at 40°C, 50°C, 60°C, 70°C, 80°C, and 90°C. The rupture point of drying time for breaking occurs at 40°C, 50°C, 60°C, 70°C, 80°C, and 90°C are 0.199 mm, 0.199 mm, 0.119 mm, 0.079 mm, 0.079 mm and 0.079 mm respectively. In the figure, with higher drying temperature, the breaking displacement shows a slight decrease in value and shows sharply decrease from 60°C to 70°C. When compare to compression test, total breaking displacement in compression is lower.

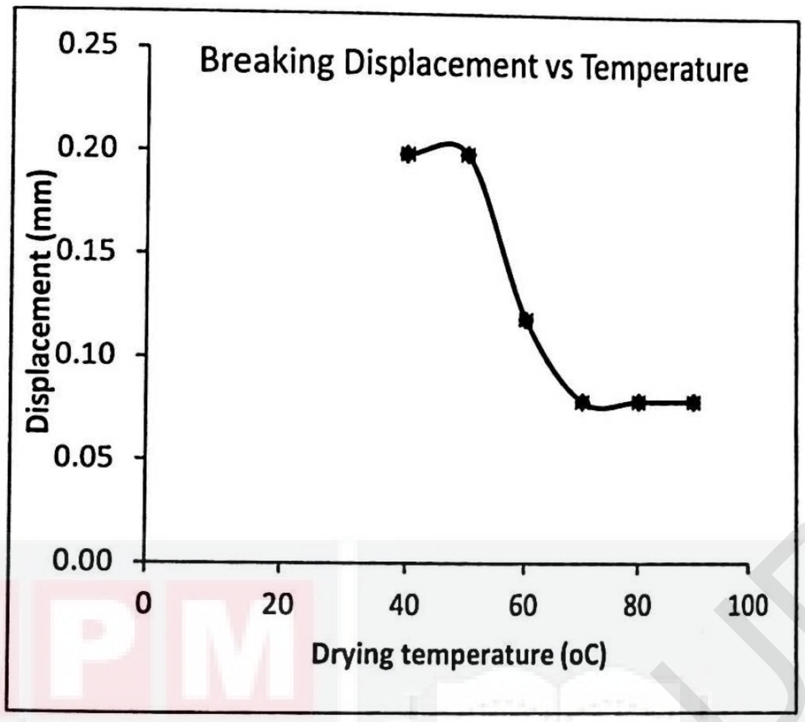


Figure 4.8: Relationship of drying temperature and displacement under three-point bending

4.5 Effect of Moisture Content on Breaking Force

4.5.1 Compression Test

Compression test was conducted to investigate the effect of moisture content and breaking force. Figure 4.9 shows the maximum breaking force that the rice kernel could sustain before rice kernel cracked. In the figure below, between MCs of 10% and 14%, 10% d.b. exhibited higher breaking force (77 N) compared to 14% d.b. (62 N) which agrees with the results reported by Kunze and Wratten (1985). Rice kernel at MC of 17% is acted as control or without drying treatment and when it is subjected to compression test, the value of breaking force is 66 N. Wouters and de Baerdemaeker (1988) explained that there is critical range of moisture content between MC of 12% and 18% where the breaking forces change drastically. This can explain by relate with moisture adsorbing environment. As heated-air enters the chamber, it gains moisture from wet grain and becomes humid. It cause these grains to adsorb the moisture until the drying front reaches them. Drying front is the area of heat and mass exchange in the rice grain bed.

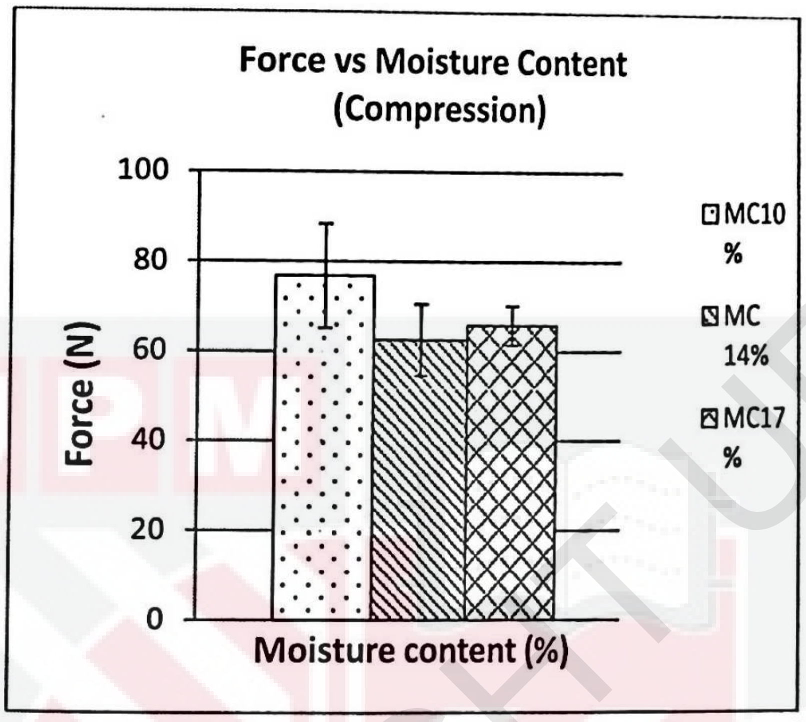


Figure 4.9: Relationship between moisture content and breaking force under compression

4.5.2 Three - point bending test

Figure 4.10 shows the maximum breaking force that the rice kernel could sustain before rice kernel cracked under three-point bending. Similar observation was found in the compression test between MC of 10% and 14%, where 10% MC needs higher breaking force which is 29 N to crack compare to 14% and 17% MC. Both 14%d.b. and 17% d.b need breaking force of 26 N and 16 N, respectively to crack. It shows that the breaking force increased with decrease of moisture content. Bamrungwong *et al*. (1988) also obtained the same results where the breaking force increased with decrease of moisture content. They obtained 15 to 18 N under moisture content of 16.4% d.b. to 18.8% d.b. which was the highest range of moisture content.

However, three-point bending test require lower force to that of compression test to crack the rice kernel. The similar explanation was applied under this method as in compression test because the rice kernel was exposed to rapid moisture adsorbing environment and caused the rice kernel to fissure *(Y. Lan et al.*, 2002).

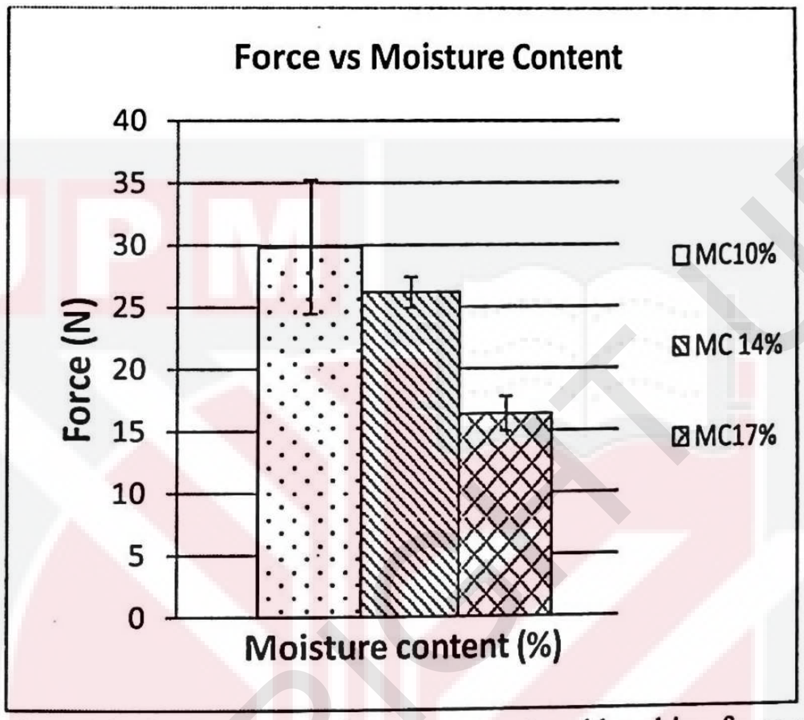


Figure 4.10:Relationship between moisture content and breaking force under three-point bending

4.6 Effect of moisture content on breaking displacement

4.6.1 Compression test

In Figure 4.11, the effect of moisture content on the breaking deformation of MR 220 was showed. Total deformation needed to break the rice kernel was defined as breaking deformation. The figure shows the mean value of breaking deformation for MCs of 10%, 14% and 17%. The rupture point of MCs for breaking occurs at 10%, 14%, and 17% are 0.33 mm, 0.36 mm and 0.388 mm, respectively. From the observation, higher percentage of moisture content resulted in higher breaking deformation. It is literally different with the result found by Bamrungwong *et al.* (1987) where the higher moisture content has lower breaking deformation for MC at 12% d.b. to 18% d.b. This is due probably to the condition of rice grains were not in good condition.

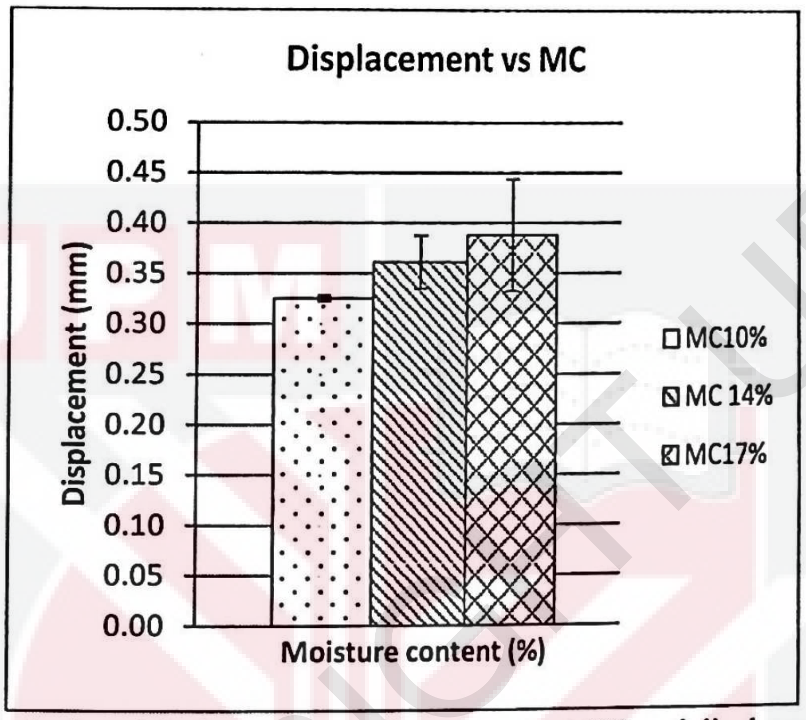


Figure 4.11:Relationship between moisture content (%) and displacement (mm)

4.6.2 Three-point bending

Figure 4.12 shows the relationship between moisture content and breaking deflection. The breaking deflection at 14% d.b. is slightly lower compare to that of 10% d.b. The breaking values obtained were 0.189 mm, 0.181 mm and 0.133 mm for MCs of 10%, 14% and 17%, respectively. It can concluded that the higher value of moisture content resulted lower breaking deflection which agrees the hypothesis made by Bamrungwong *et al.* (1988). They also obtained lower breaking deflection at higher value of moisture content. Shimizu *et al.* (1974) obtained 38 to 43.8 µm at range of moisture content 11.6 to 20.5%. The values may differ due the differences in variety, physical dimension, and span.

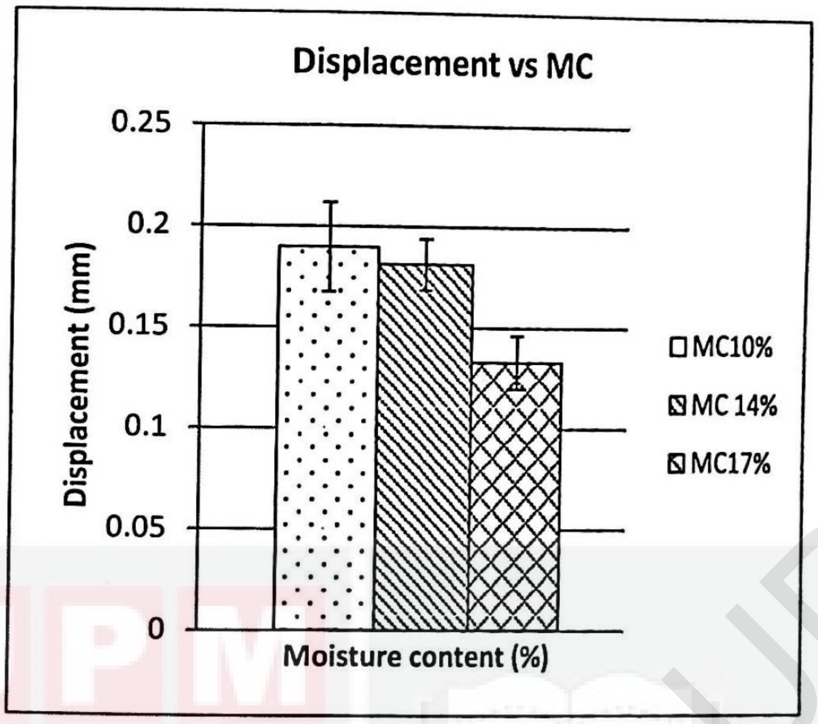


Figure 4.12:Relationship between moisture content (%) and displacement (mm)

4.7 Imaging of Fracture Surface of Rice Grains

4.7.1 Dino-Lite digital microscope

Figures 4.13 show the images of rice kernels under dino-lite digital microscope at drying temperature of 40°C 90°C for first and fifth hours of drying. For Figure 4.13 (b) and (c), the rice kernels show no difference compare to Figure 4.13 (a), which is the rice kernel without drying treatment. Thus, it can be concluded that there is no formation of fissure at drying temperature of 40°C for first and fifth hours of drying. However, Figure 4.13 (d) and (e) show the formation of fissure for rice dried at 90°C for first and fifth hours of drying. The fissures formed is due to exposure of rice kernels to extreme drying temperature and lead to temperature difference between drying air and rice kernels. Arora *et al.* (1973) stated that the drying air temperature should be below 53°C to reduce the kernel thermal stress that lead to the development of fissures. Since rice dried at 40°C which is below temperature of 53°C show no fissure formation within the rice kernels, this observation agrees the result found by Arora *et al.* (1973). Thus, Dino-lite test can be a useful equipment to study the formation of fissure in dried rice kernels.

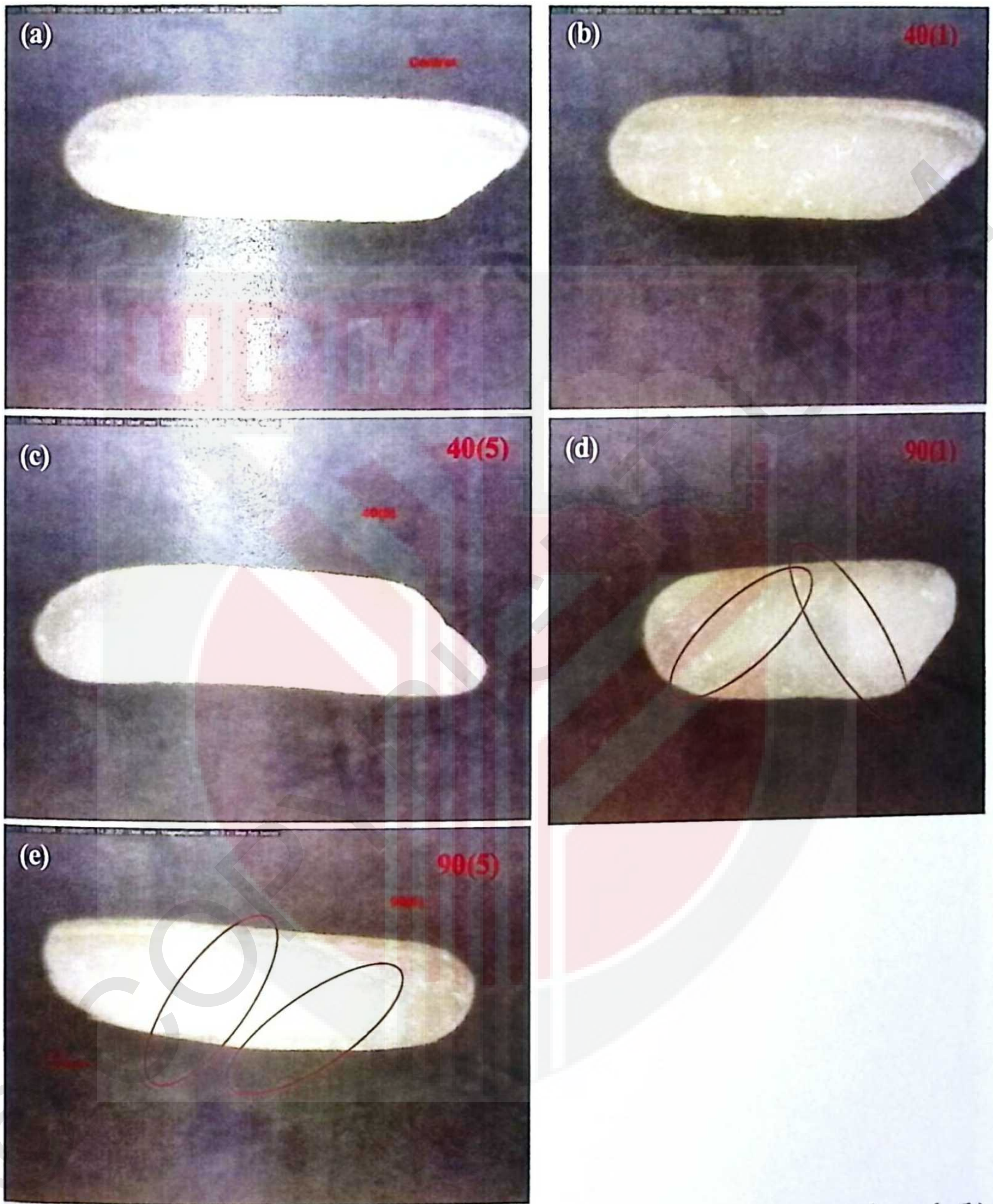


Figure 4.13: Photograph of rice kernel from Dino-lite microscope (a) Control sample (b) 40°C for 1st hour drying (b) 40°C for 5th hours drying (c) 40°C for 1st hour drying (d) 40°C for 5th hours drying

4.7.2 Scanning electron microscope

Figures 4.14 show the surface rice grain without drying treatment which act as a control to make a comparison other samples. The surface of the control sample is almost similar to the result in Figure 4.15 when viewed at low magnification. The outer layer for both control and dried rice grain at first hour drying of 40°C is smooth without any fracture layer. When highest magnification (2000x) is used, the results showed no tear or fissure layer between both samples. The result is different with observation made by Craufurd (1963) where there is no fissure in the rice grain for first half hour of drying and fissures start developed after 1 hour of drying.

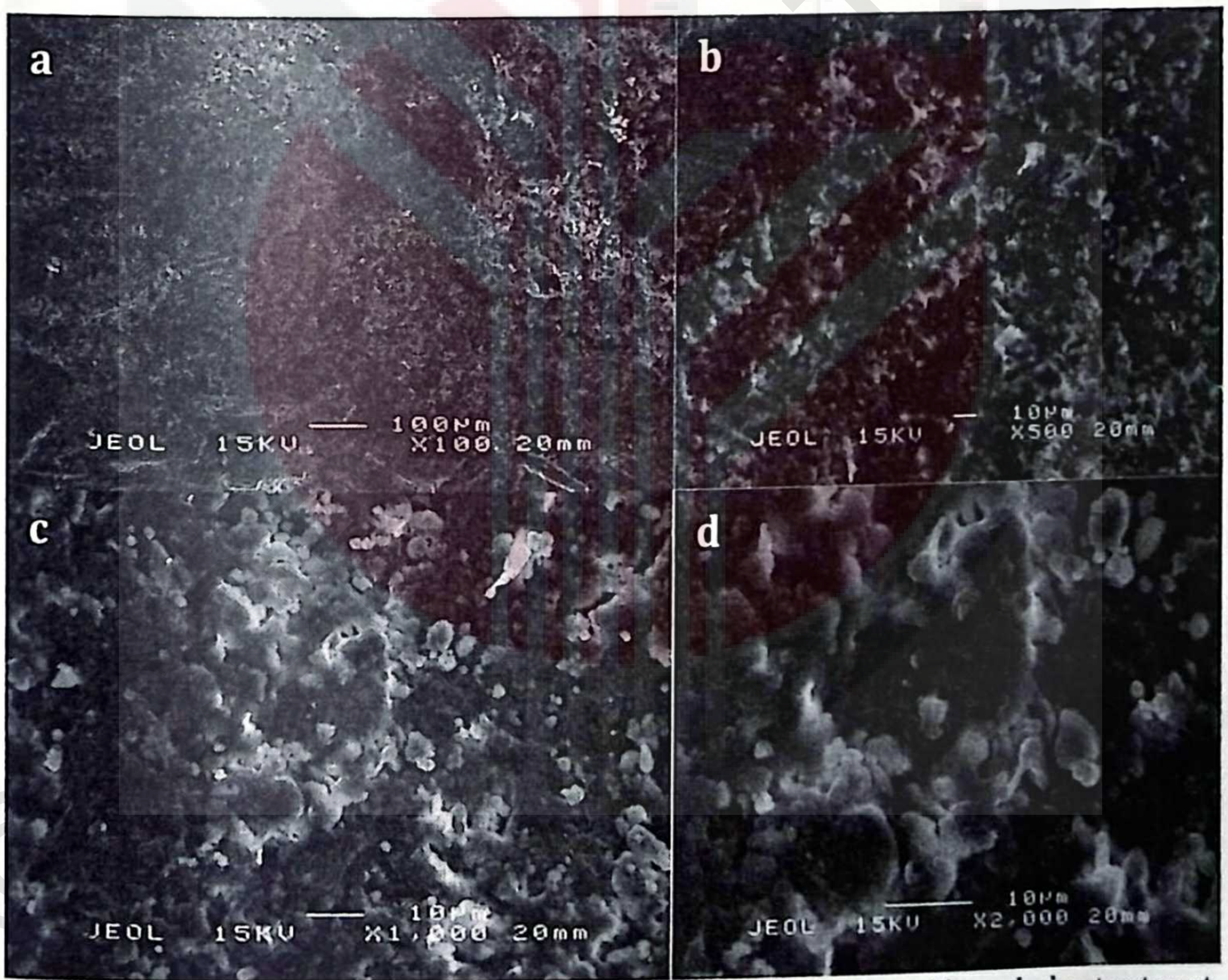


Figure 4.14: SEM images of rice grain surface without drying treatment.
(a) x100 (b) x500 (c) x1000 (d) x2000

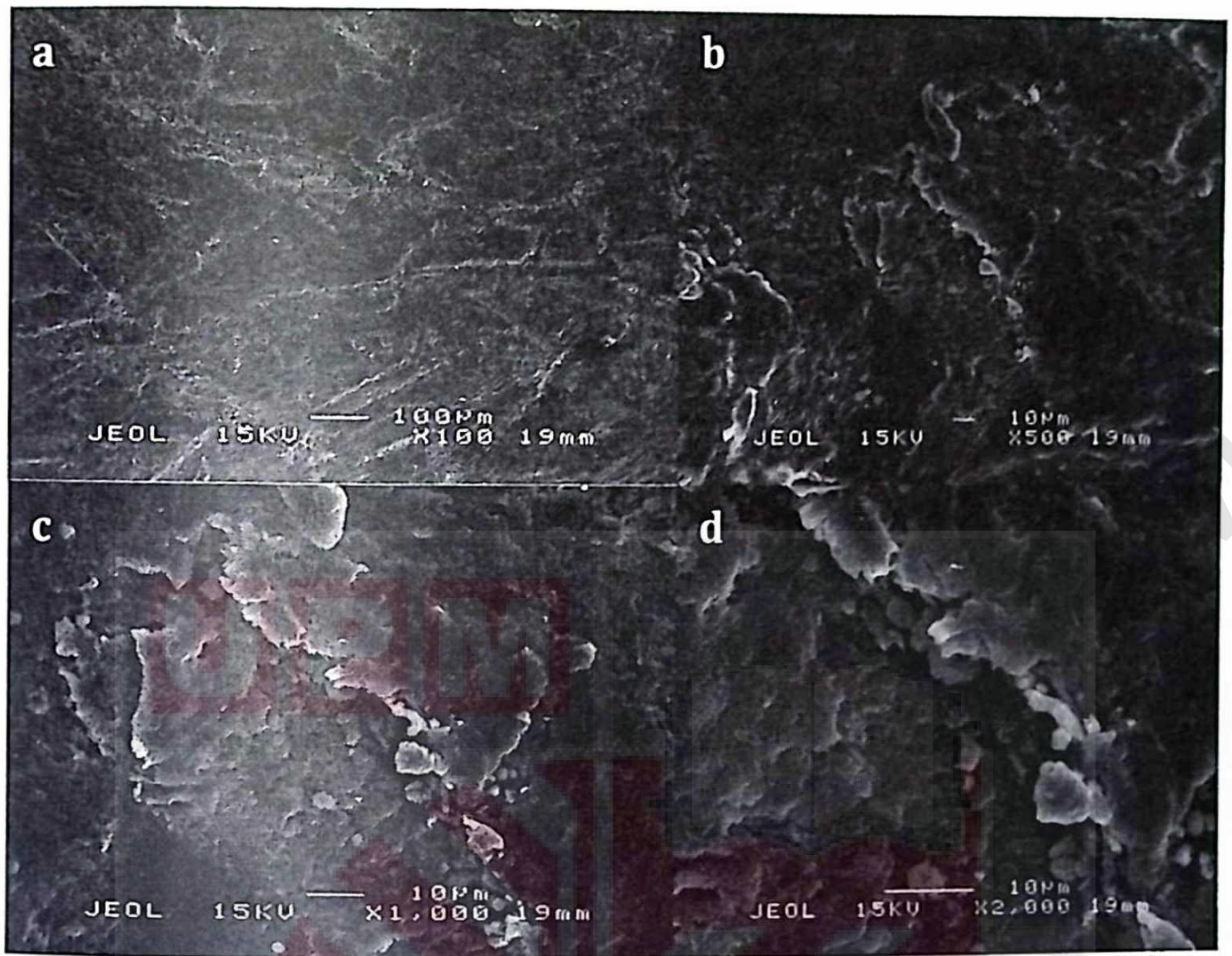


Figure 4.15: SEM images of rice grain surface after first hour drying at 40°C.
(a)x100 (b) x500 (c) x1000 (d) x2000

Figures 4.16 show the surface of rice grain at drying temperature of 40°C after 5 hours drying under four different magnifications. At lower magnification (100x and 500x), the photomicrograph shows short linear line at the edge of the external surface of the rice grain. Under 2000x magnification, it can be clearly observed that finer tear formed along the surface which may probably be fissure. The starch granule also were loose and not compact as compare to the control sample. It can be concluded that the fissure is started to develop at temperature of 40°C for 5 hours drying.

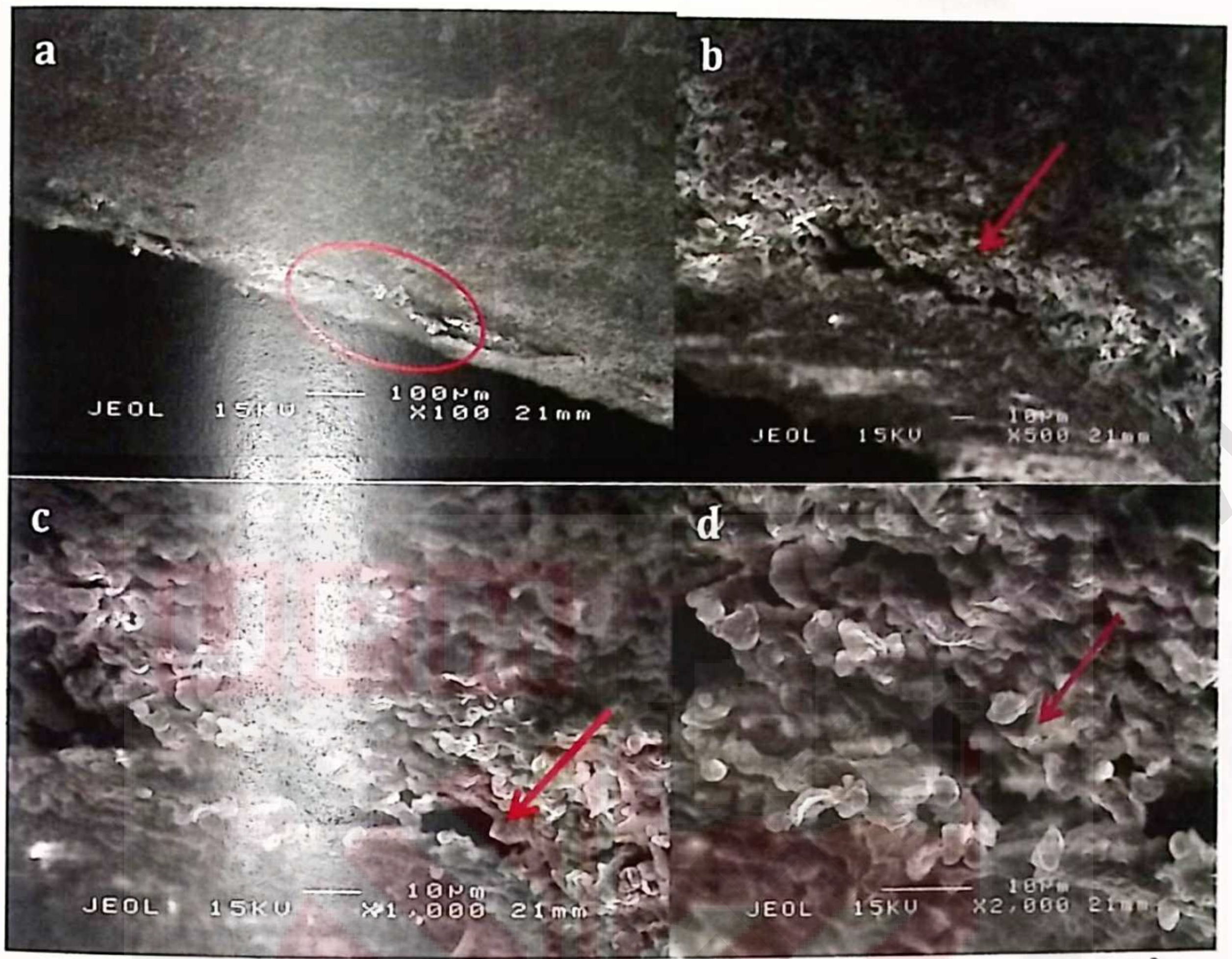


Figure 4.16: SEM images of rice grain surface after fifth hour drying at 40°C (a)x100 (b) x500 (c) x1000 (d) x2000

Figures 4.17 show the surface or rice grain at drying temperature of 90°C for first hour drying under different magnifications (100x-2000x). At lower magnification (100x and 500x), fissure can be seen formed along its long axis. Under higher magnification of 1000x and 2000x, it can be clearly observed the void between the fractured layers. The fissure pattern is similar to Figure 4.16 but the size of crack is larger than that in Figure 4.16.

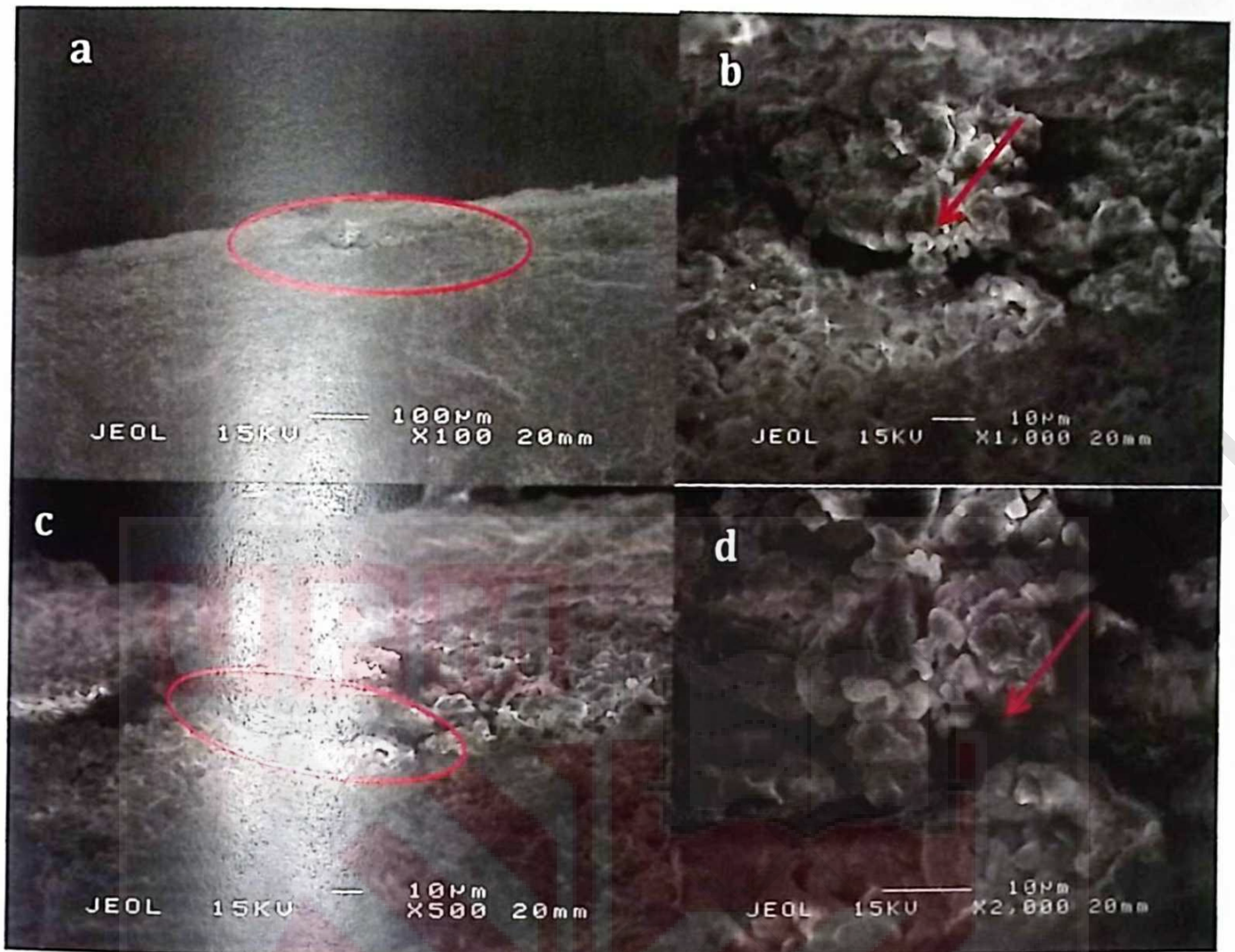
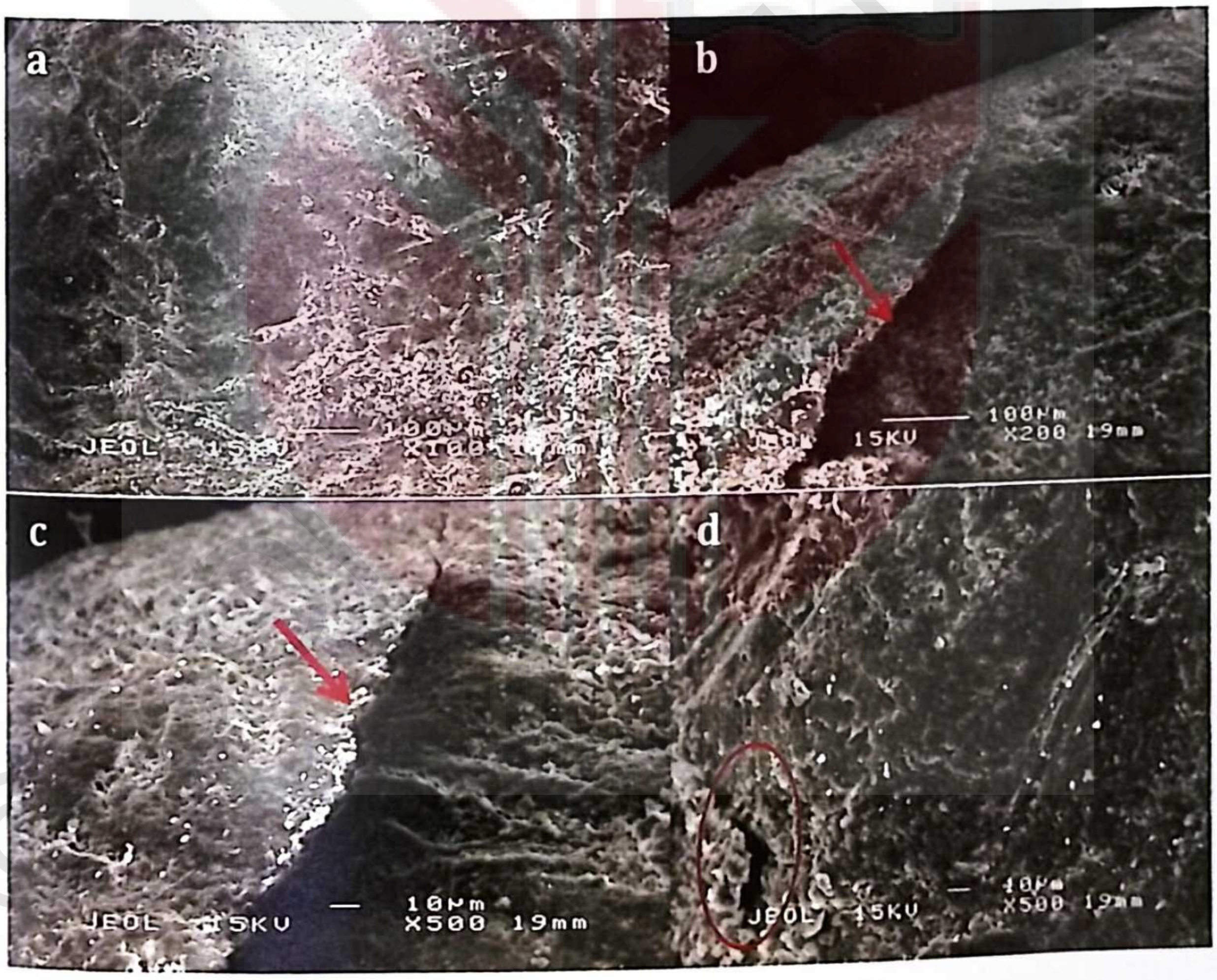


Figure 4.17: SEM images of rice grain surface after first hour drying at 90°C. (a)x100 (b) x500 (c) x1000 (d) x2000

Figures 4.18 show the surface of rice grain at drying temperature of 90°C for 5 hours drying time under different magnifications (100x to 2000x). At this condition, fissure can be seen on the outermost. Many fissures can be seen and it is scattered around the surface. The fissure pattern under this condition is different compare to other temperature where there are fissures along horizontal and long axis, while fissure pattern in Figure 4.16 and Figure 4.17 develop along its long axis. Many voids are observed between the fracture layers.

The voids space between starch granules serves as water channel into the grain. Thus, uneven moisture gradient is occurred which cause the outer surface of the grain to expand while inner of the grain contract and shrink. These simultaneous actions will produce the fissured grain across its long axis from center to the surface (Kobayashi *et al.*, 1972). Henderson (1954) reported that the small fractures expanded into larger cracks or fissures when the rice grain was continue to dry. This hypothesis agrees with result obtained for sample dried within 1 and 5 hours where more fissures are developed (Figure 4.18). This is because moisture adjacent to a fissure grain can move to the grain surface more easily than moisture in an unfissured grain. When the internal surface of the rice grain continued to dry, the internal section contracted as tensile stress is produced within the rice grains and developed fissures (Kunze, 1964).



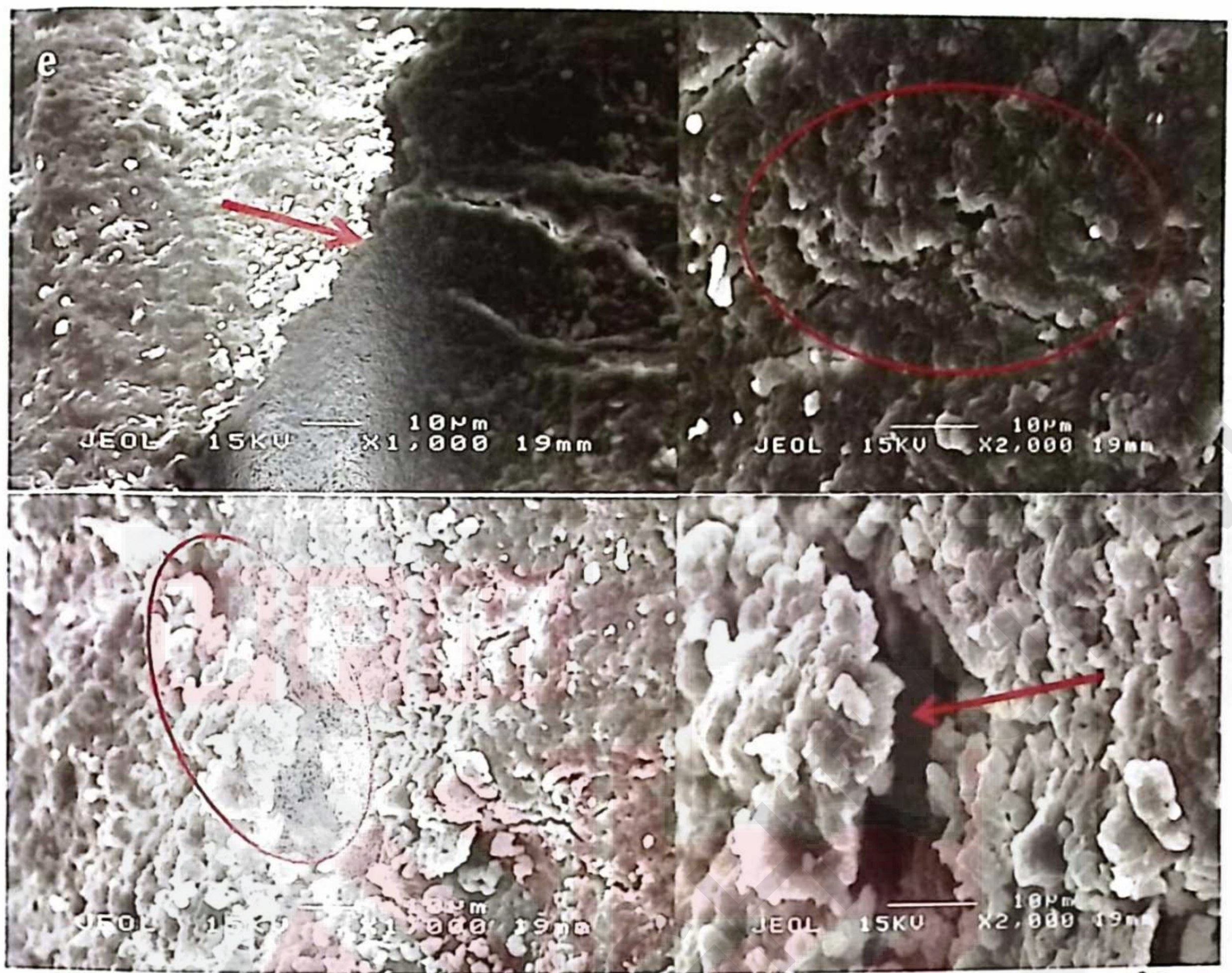


Figure 4.18: SEM images of rice grain surface after fifth hour drying at 90°C (a)x100 (b) x200 (c) x500 (d) x500 (e) x1000 (f) x 2000 (g) x1000 (h) x2000

4.8 Summary

Two methods are used to identify formation of fissures in rice grains which are using Dino-lite digital microscope and Scanning Electron microscope. Both methods showed the fissure formation at highest temperature which is 90°C. However, Dino-lite digital microscope is not able to detect formation of fissure at 40°C due to probably the fissure is too small for Dino-lite to detect. SEM provides details on the surface information and even at lowest temperature, the equipment can detect the small fissure. These observations are related to the mechanical properties of rice grains. At 90°C for fifth hours of drying , the breaking force is the lowest for crack or rupture to occur. This is due to formation of larger fissure compare to others temperature and it is easy to crack when subjected to mechanical test.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In order to obtain basic information on the mechanical properties of rice kernels and effect of drying temperature on the rice kernel, compression test and three-point bending test were conducted using MR 220 variety.

From this research, the hygroscopic behavior of rice kernels which it is easily adsorb or desorb moisture when it is from one temperature to another temperature had been proved. This can be observed on rate of moisture loss during drying. The moisture content is decreased as drying proceeds from 1 hour to 5 hour. The highest rate of moisture loss is at 90°C (0.94% d.b./hour) the lowest rate of moisture loss is at 40°C (0.42%d.b./ hour). The moisture loss showed that rice kernel is in moisture-desorb environment where the water is released in the form of vapor.

The higher the drying temperature, the lower breaking force needed for compression test and three-point bending. Compression test showed higher breaking force needed compared to three-point bending. However, drying temperature does not had a significant effect on breaking force in compression compare to bending test. Therefore, three-point bending method is considered as most suitable method to determine mechanical properties of the rice kernel.

The effect of drying temperature on the breaking displacement also were investigated using compression and three-point bending test as well. Both tests showed that higher temperature needs lower breaking displacement to crack the rice kernels. However, the value of breaking displacement is higher compare to three-point bending. The breaking displacement range for compression is 0.316 mm- 0.349 mm while for three-point bending is 0.079 mm – 0.199 mm.

The effect of moisture content on the breaking force for both mechanical tests showed different results. For compression test, the lowest breaking force needed to crack the rice grain is at MC of 14% d.b. while in three-point bending, the lowest breaking force is at MC of 17% d.b. This showed that compression is not best method to study on mechanical properties of rice grains compare with three-point bending. Effect of moisture content on breaking deflection was analyzed and it showed higher moisture content need lower breaking displacement for both compression and three-point bending.

The photomicrograph of rice kernel from scanning electron microscope are different for each temperature. At fifth hour of 90°C shows the most fissured layer between the endosperm. For first hour of 40°C shows no fissure as the surface of rice kernel is smooth and the starch granule also more compact compare to 90°C which is more looser. This is difference by using Dino-lite digital microscope because it is only showed fissure at highest temperature of drying. Since, the SEM images revealed clearly structural details of fissure formation in the rice kernels, it makes SEM a useful method compare with Dino-lite to determine or analyze fissure development in the rice kernels. Thus, this research objectives has successfully determined.

5.2 Recommendations for Future Research

Although the basic informations about mechanical properties of the rice kernels are agrees with the published journal, these information are not enough to improve the milling quality. Other mechanical properties such as tensile strength, modulus of elasticity, modulus of toughness and strength of rice kernels are also needed for better development of milling process. This research also can be continued by investigate the effect of drying temperature on head rice yield. Head rice yield is one of the important quality in milling operation because producing milled rice with high HRYs is consider high rice quality.

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APPENDICES

Table A.1: Moisture content of rice grains at different temperature

Time (h)	Temperature (°C)					
	40	50	60	70	80	90
0	15.1	14.8	14.7	14.7	14.7	14.7
1	14.2	13.7	12.7	12.2	12.3	11.7
2	13.8	12.5	11.4	11.2	11.0	11.0
3	13.5	12.1	11.0	10.8	10.7	10.5
4	13.0	11.6	10.7	10.4	10.4	10.5
5	12.6	11.0	10.5	10.3	10.4	10.4

Table A. 2: Breaking force at different temperature using compression test

Temperature (°C)	Breaking Force (N)
40	84.45
50	82.64
60	80.69
70	78.98
80	75.60
90	73.50

Table A.3:Breaking force at different temperature using three-point bending test

Temperature (°C)	Breaking Force (N)
40	34.11
50	33.12
60	16.49
70	9.52
80	9.04
90	8.78

Table A.4: Breaking displacement at different temperature using compression test

Temperature (^oC)	Displacement (mm)
40	0.349
50	0.3403
60	0.3356
70	0.324
80	0.31967
90	0.316

Table A.5: Breaking displacement at different temperature using three-point bending test

Temperature (^oC)	Displacement (mm)
40	0.199
50	0.199
60	0.119
70	0.079
80	0.079
90	0.079

Table A.6: Breaking force at different MC using compression test

Moisture content (d.b.%)	Breaking Force (N)
10	77
14	62
17	66

Table A. 7: Breaking force at different MC using three-point bending test

Moisture content (d.b.%)	Breaking Force (N)
10	30
14	26
17	16

Table A. 8: Breaking displacement at different MC using compression test

Moisture content (d.b.%)	Displacement (mm)
10	0.33
14	0.36
17	0.39

Table A.9: Breaking displacement at different MC three-point bending test

Moisture content (d.b.%)	Displacement (mm)
10	0.133
14	0.181
17	0.190

Figure A.1: Fresh Harvested Paddy

Figure A.2: Paddy husk

Figure A.3: Milled Rice

Figure A.4: Kett Single Kernel Moisture Meter