**UNIVERSITI PUTRA MALAYSIA**

# *EFFECT OF PARTICLE SIZE AND COMPRESSIBILITY ON THE FLOWABILITY OF WHEAT, CORNSTARCH, TAPIOCA AND ATTA FLOURS*

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# EFFECTS OF PARTICLE SIZE AND COMPRESSIBILITY ON THE FLOWABILITY OF WHEAT, CORNSTARCH, TAPIOCA AND ATTA FLOURS

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| | |
|---|---|
| $\rho_b$ | Bulk Density |
| $\rho_t$ | Tapped Density |
| $\rho_s$ | True Density |
| $\varepsilon$ | Porosity |
| $HR$ | Hausner Ratio |
| $CI$ | Carr Index |
| $UYS$ | Unconfined Yield Strength |
| $MPCS$ | Major Principle Consolidating Stress |
| $\phi_w$ | Angle of wall friction |
| $\delta$ | Angle of internal friction |
| $ffc$ | Flow function index |
| $\theta$ | Hopper angle |
| $B$ | Minimum outlet diameter |
| $\sigma_{crit}$ | Sigma Critical |
| $M_W$ | Mass of wet sample |
| $M_D$ | Mass of dry sample |

# ABSTRACT

Four types of commercial flour were used in this project which are wheat flour, cornstarch flour, tapioca flour and atta flour. This research is conducted to investigate the flow and the effect of physical properties of flours and their relationship to design the outlet diameter of hopper flow. The flowability and the cohesiveness of the powders are determined using Carr index and Hausner Ratio. The flow properties were measured using shear cell technique, and the physical properties measure were particle size, moisture and densities (bulk, tapped and true). The compressibility is done by direct compression using uniaxial die compaction. A shear cell test give result flow factor index, varied from easy flow to very cohesive. It was found that the atta and wheat flours were very cohesive powder with highest particle size (173.96 ± 2.12 μm) and (140.93 ± 4.63 μm) respectively whereas cornstarch and tapioca cohesive powder with lowest particle size (22.05 ± 0.08 μm) and (21.88 ± 0.05 μm) respectively. The shear cell test also can give result to calculate the outlet diameter of hopper flow. The most cohesive powder was found in atta flour with Carr index (42.68 %) due to its high content fat that reduced the flowability. As for hopper flow design the diameter of each powder was determined. The largest outlet diameter of hopper flow was atta flour (0.24 m). This study show that fat content was the major influence of flowability instead of particle size and compressibility. Thus, atta flour was the most cohesive powder between wheat, cornstarch and tapioca flour. Atta flour had the highest value of carr index, hausner ratio and lowest flow factor index that indicated its flowability was the poorest. Thus, this study is very helpful in understanding of flowability of powders and can be applied in industry application.

# ABSTRAK

Empat jenis tepung komersial digunakan dalam projek ini iaitu tepung gandum, tepung jagung, tepung tapioca dan tepung atta.Kajian ini dijalankan untuk mengkaji aliran dan kesan sifat fisikal dan kimia tepung dan hubungan mereka untuk mereka bentuk aliran corong. Kesan aliran dan kesepaduan serbuk ditentukan menggunakan Carr indeks dan "Hausner Ratio". Ciri-ciri aliran diukur menggunakan teknik sel ricih, dan ukuran sifat fizikal adalah saiz zarah, kelembapan dan ketumpatan. Kampatan dilakukan dengan pemampatan langsung menggunakan *"Uniaxial Die Compaction"*. Ujian sel geseran memberikan indeks faktor aliran hasil, berbeza dari aliran mudah hingga sangat padu. Tepung atta dan tepung gandum adalah serbuk yang padat dengan saiz zarah tertinggi (173.96 ± 2.12 μm) dan (140.93 ± 4.63 μm) manakala tepung jagung dan tepung ubi mepunyai saiz zarah terendah (22.05 ± 0.08 μm) dan (21.88 ± 0.05 μm) masing-masing. Serbuk yang paling kohesif ditemui dalam tepung atta dengan Carr indeks (42.68%) kerana mempunyai kandungan lemak yang tinggi menyebabkan pengaliran serbuk menurun. Bagi reka bentuk aliran corong, diameter setiap serbuk ditentukan. Diameter aliran corong tertinggi ialah tepung atta (0.24 m). Kesimpulannya, kajian ini menunjukkan bahawa kandungan lemak adalah pengaruh utama aliran dan bukannya saiz zarah. Oleh itu, tepung atta adalah serbuk yang paling padat antara tepung gandum, tepung jagung dan tepung tapioka. Tepung atta mempunyai nilai tertinggi Carr indeks, nisbah hausner dan indeks faktor aliran terendah yang menunjukkan pengaliran serbuknya adalah yang termiskin. Oleh itu, kajian ini sangat membantu dalam memahami aliran serbuk dan boleh digunakan dalam aplikasi industri.

# CHAPTER 1: INTRODUCTION

## 1.1 Research Background

Flour is a food powder that finely ground powder prepared from grain or other starchy plant foods. Flour can be made from a wide variety of plants, the vast majority is made from wheat. Flour contains a high proportion of fat and starches, which are a subset of complex carbohydrates also known as polysaccharides. Food powders are mostly used in households all around the world and are considered among the most difficult materials to characterise. Powders are the least predictable of all materials in relation to flowability because of the large number of factors that can change their rheological properties. Their flow properties or rheology may be affected by perhaps 100 or more factors (Jan, 2015). A simple definition of powder flowability is the ability of a powder to flow (Prescott and Barnum, 2000).

The flow properties of powders are important in manufacturing operations, which are determined by a combination of physical and chemical powder characteristics, e.g., moisture content, densities, particle size, porosity as these conditions dictate the behaviour of the powder when transporting through a hopper orifice formation (Sinka et al., 2004). Powder property measurement is important because these properties intrinsically affect powder behaviour during storage, handling and processing. Powder flow properties are important in handling and processing operations, such as flow from hoppers and silos, transportation, mixing, compression and packaging (Knowlton et al., 1994).

Caking and cohesion properties also an important characteristics to determine the flowability of powders. Caking is a deleterious phenomenon by which amorphous food powders are transformed into a sticky undesirable material, resulting in loss of functionality and lowered quality (Aguilera, 1995). Caking can result in different composites, ranging from small, soft aggregates that can be broken easily to rock-hard lumps aggregates that need a sledgehammer to disperse (Barbosa et al., 2005). Cohesiveness is the tendency of the powder particles to cling together and agglomerate. The Jenike shear test method was utilized in this study, as the most significant type of flowability process seems to be the shear test, in which the force required to shear a powder under well-defined conditions is determined. The Jenike's shear test is a combination of normal and shear stress analysis in developing an engineering standard methodology as a basic in determining the minimum hopper angle and hopper opening size for mass flow (Jenike, 1964).

The present study has been conducted with the commercial flour which has been assessed for particle size analysis, bulk density, tapped density, true density, porosity, moisture content, caking strength, cohesion index, powder flow speed dependency test and shear test.

## 1.2 Problem Statement

Flour is a product that is used in all households. Since it is used everywhere, it becomes an important part of everyone's lives and should be packaged, transported and handled carefully. The study of powder properties and flowability of powder is important in order to know the flowability of flour and to design the hopper design to move flour from one receptacle to another. Hopper design is important to ensure the flowability of flour is going smoothly without having problems. Designing the hopper, we need to understand about the powder flowability, powder compressibility and compactibility, powder caking and cohesion. The physical and chemical properties of powder also a crucial properties that need to study in order to determine the flowability of the powder. Particle size, caking and cohesion are major problems which can contribute to reduce product quality, functionality, and shortened shelf life. Particle size and the ability of the powder to compress also can contribute in investigating the flowability of powders. The study of particle size of each type of flour is less. Next, less study of hopper design in flour industry cause all types of flour cannot discharge adequately from the opening hopper or flour segrates during the flow. The most vulnerable industrial powder problems are obtaining reliable and consistent flow out of hoppers and feeders without excessive spillage and dust generation. These problems are usually associated with the flow pattern inside the silo and hoppers. The worst-case scenario is no flow. This can occur when the powder forms a cohesive arch across the opening, which has sufficient strength within the arch to be self-supporting.

## 1.3 Objectives

The general objective of this study is to evaluate on the effect of particle size and compressibility on flowability of flours. Along with the main objective, there are several specific objectives including:

I. To investigate the effect of particle size and compressibility on flowability of wheat, cornstach, tapioca and atta flours.

II. To calculate the hopper design for each of the powders.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Flour Powders

### 2.1.1 Wheat Flour

Wheat flour is a powder made from the grinding of wheat used for human consumption. Wheat varieties are called "soft" or "weak" if gluten content is low, and are called "hard" or "strong" if they have high gluten content. Hard flour, or bread flour, is high in gluten, with 12% to 14% gluten content, and its dough has elastic toughness that holds its shape well once baked. Soft flour is comparatively low in gluten and thus results in a loaf with a finer, crumbly texture (Bass and Pomeranz, 1988).

### 2.1.2 Cornstarch Flour

Cornstarch is the starch derived from the corn (maize) grain. The starch is obtained from the endosperm of the kernel. Corn starch is a common food ingredient, used in thickening sauces or soups, and in making corn syrup and other sugars. It is versatile, easily modified, and finds many uses in industry as adhesives, in paper products, as an anti-sticking agent, and textile manufacturing (Whistler et al., 1984). It has medical uses, such as to supply glucose for people with glycogen storage disease (Gremse et al., 1990).

### 2.1.3 Tapioca Flour

Tapioca is a starch extracted from cassava root. It consists of almost pure carbs and contains very little protein, fiber or nutrients. Tapioca is popular as a gluten-free alternative to wheat and other grains.

### 2.1.4 Atta Flour

Atta flour is a wholemeal wheat flour, originating from the Indian subcontinent, used to make flatbreads such as chapati, roti, naan, paratha and puri. Hard wheats, used to make atta, have a high gluten content, which provides elasticity, so doughs made out of atta flour are strong and can be rolled out into thin sheets.

## 2.2 Flowability of Powders

Flowability is the ability of granular solids and powders to flow. Flow behaviour is multidimensional in nature, and it depends on many physical characteristics. Flowability, in fact, is a consequence of the combination of a material's physical properties that influence material flow, environmental conditions, and the equipment used for handling, storing, and processing these materials (Prescott and Barnum, 2000). A full understanding of powder-flow behaviour is essential when addressing segregation problems. A simple definition of powder flowability is the ability of a powder to flow. By this definition, flowability is sometimes thought of as a one-dimensional characteristic of a powder, whereby powders can be ranked on a sliding scale from free flowing to non-flowing.

### 2.2.1 Carr Index and Hausner Ratio

Powder flow properties of food powders highlights the importance of flowability parameter for a powdered material measured by the Carr index and Hausner ratio which it all depends on the physical properties of the powders such as the particle size and shape, surface structure, particle density, and bulk density. The crucial properties that affect the value of Carr Index and Hausner ratio were depends on the densities; bulk density and tapped density. These density play a significant role to determine the flowability of powder. Flowability is very crucial parameter for a powdered material measured by Carr index and Hausner Ratio.

## 2.3 Physical Properties of Powders

There are many types of physical properties. The physical powder properties that measured in this study are particle size, bulk density, tapped density, true density and porosity and moisture content (wet basis and dry basis).

### 2.3.1 Particle Size, Densities and Porosity

In many powder handling and processing operations particle size and size distribution play a key role in determining the bulk properties of the powder. Describing the size distribution of the particles making up a powder is therefore central in characterizing the powder. In many industrial applications a single number will be required to characterize the particle size of the powder. Particle size has a major influence on powder flowability. The reduction in flowability to smaller particle size is due to the increased surface area per unit mass of powder. More surface area is available for cohesive forces, in particular, and frictional forces to resist flow. Intuitively, one would expect particle shape to affect flowability, as shape will influence the surface contacts between particles. Smaller particle size contributed to the reduced flowability as, the particle surface area per unit mass increased with decreased particle size providing a greater surface area for cohesive forces to interact which results in cohesive flow (Fitzpatrick et al., 2004).

An increase in particle size generally leads to an increase in compressibility (and thus volume reduction) (Yan and Barbosa, 1997). In a mass flow scenario, if the particles are less than 1/4 inch in size, then cohesive arching will occur during discharge (Marinelli and Carson, 1992). The finer the particle size and greater the range of particle sizes, the greater the cohesive strength, and lower the flow rate (Marinelli and Carson, 1992). Reduction in size increases the contact area between the particles, thereby increasing the cohesive forces. In conclusion, the smaller the particle size, the poorer the flowability of powder. However, particle size is not the only factor that affecting the flowability of powder. Many others factor can be major influence that affect the flowbility of powder.

Density is the measurement of how much mass is contained in a given unit volume. The density of food material is used by the industry to adjust storage, processing, packaging and distribution conditions. In addition, density also relate with to the movement of the particle and the porosity of the particle. There are three different types of density to measure the flowability of powder, which are; bulk density, tapped density and true density. Bulk density is the ratio of the mass of powder bed in a vessel to the volume of the powder occupied in the bed before tapping. Tapped density is the ratio of the mass of the powder bed in a vessel to the volume of the powder bed after tapping (until reach constant). True density represents the mass of the particle divided by its volume excluding open and closed pores. Porosity or void fraction is a measure of the void ("empty") spaces in a material, and is a fraction of the volume of voids over the total volume.

### 2.3.2 Moisture Content

Powder's moisture content also usually has significant impact on its flowability. When the moisture content increasing leads to reduced flowability due to increase in liquid bridges and capillary forces acting between the powder particles (Scoville and Peleg, 1981). Most organic granular materials are hygroscopic in nature, and they gain or lose moisture when they are exposed to various humidity conditions. Moisture sorption is often coupled with increased cohesiveness, chiefly because of inter particle liquid bridge formation. Moisture content thus affects the cohesive strength and arching ability of bulk materials. As the moisture content of a powder increases, the adhesion (Craik and Miller, 1958) and cohesion (Moreyra and Peleg, 1981) tend to increase. Even a small change in moisture content can substantially affect the frictional properties (e.g., wall friction angle, internal angle offriction) of material (Marinelli and Carson, 1992).

The powder surface composition, such as fat, protein, moisture content also affects the flow ability of powder. The variation in the flow ability of the fruit powders was due to the powder particle morphology (different article sizes and shapes of the flour powder particles) and the interaction of the particles. When the powder contains particles of different sizes, then the smaller particle fill the void spaces created by the larger particles.

## 2.4 Caking, Cohesion and Powder Flow Speed Dependency (PFSD) properties

The powder flow analyser can analyze properties like the caking strength, cohesion index and stability index of the powders. Caking is a deleterious phenomenon by which amorphous food powders are transformed into a sticky undesirable material, resulting in loss of functionality and lowered quality. Caking is a powder's tendency to form lumps or masses. The formation of lumps interferes with packaging, transport, flowability, and consumption (Mingyang et al., 2018). Usually caking is undesirable, but it is useful when pressing powdered substances into pills or briquettes. Granular materials can also be subject to caking, particularly those that are hygroscopic such as salt, sugar, and many chemical fertilizers. Caking mechanisms depend on the nature of the material. Caking is a consequence of chemical reactions of grain surfaces. Often these reactions involve adsorption of water vapour or other gases. This show the higher ability of powder to caking, will reduce the flowability of powder.

Cohesivity of powders influences the flow of powders and sometimes causes difficulties in powder flow. Cohesiveness is the tendency of the powder particles to cling together and agglomerate. Cohesion index is defined as the ratio cohesion coefficient/sample weight. Low cohesion index is associated with non-cohesive free-flowing powders. High cohesion index is associated with cohesive, poor flowing powders. Table 2.1 show the classification of cohesion index (*CI*).

**Table 2.1** Classification of Cohesion Index (*CI*) (Abdullah et al., 2010).

| Cohesiveve Index (*CI*) | Flow behaviour |
|---|---|
| >19 | Hardened/ extremely cohesive |
| 19-16 | Very cohesive |

| | |
|---|---|
| 16-14 | Cohesive |
| 14-11 | Easy-flowing |
| <11 | Free-flowing |

Powder flow speed dependency (PFSD) was analyzed to quantify the dependency of flow characteristics on flow rate for powders. It also measures flow stability or how the powder breaks down during testing. PFSD measures the flow stability index i.e. the interparticle friction of the powder. The stability index >1 means the product has changed during testing (giving a higher compaction coefficient), if <1 means it has changed giving it a lower compaction coefficient (Shah et al., 2008). An increase in the compaction coefficient as the test speed increases indicates increasing resistance to flow and therefore flow speed. A decrease in the compaction coefficient with increasing flow speed would mean that the powder becomes freer flowing with increasing flow speeds dependency (Benkovic and Bauman, 2009).

## 2.5 Compressibility

Particle size and shape have considerable impact on the compressibility and is considered as an important parameter for bulk handling. Though it is not a direct measure of flowability but can be used for predicting whether the flour is free flowing or cohesive. Compressibility is the ability to reduce volume, and compactability is the ability to form particle bonding. The general principle is to derive quantitative data specific to the material by interpreting the curves relating pressure to volume reduction, or pressure to residual porosity (Kawakita and Lűdde, 1971). High compressibility is often associated with high cohesivity of the powders in addition to other factors such as bulk density and packing structure (Jan et al., 2017). Uniaxial die compaction is a compaction process of a powder within a die cavity by the action of an upper punch at a constant velocity, while the lower punch does not move within the mechanical assembly Figure 2.1. This process is particularly important to investigate the compressibility and compactability of powder. Compressibility is the ability to reduce volume, and compactability is the ability to form particle bonding (Yusof et al., 2010).

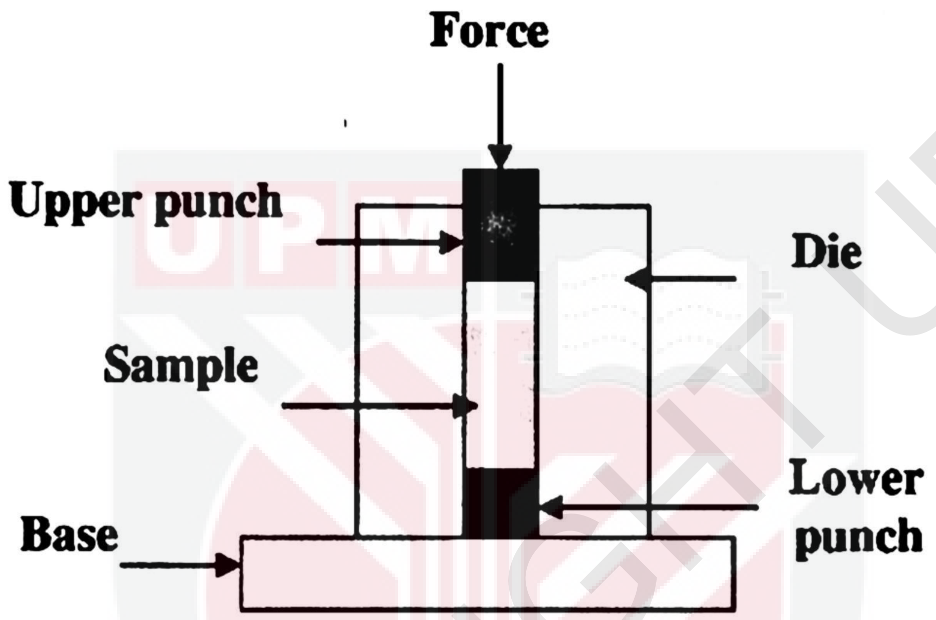

**Figure 2.1** A schematic diagram of uniaxial die compaction (Yusof et al., 2010).

## 2.6 Hopper Design

Hoppers are used in industry for protection and storage of powdered materials. Hoppers must be designed such that they are easy to load. More importantly, hoppers must be designed such that they are easy to unload. The way the hopper is designed affects the rate of flow of the powder out of the hopper, if it flows at all. Also, the way the hopper is designed affects how much of the stored material can discharge and whether there mixing of solid sizes or dead space that reduces the effective holding capacity of the hopper. These issues and others discussed here are important to consider when designing storage hoppers. There are two primary and distinct types of flow of solids in hoppers, mass flow and funnel flow. There is also a special case that is a combination of these two flows called expanded flow. These flows get their names from the way in which solids move in the hoppers.

The characteristics and differences between the flows are depicted in Figure 2.2. The primary difference between mass and funnel flow is that in mass flow all of the material in the bin is in motion, though not necessarily all with the same velocity. In funnel flow only a core of material in the center above the hopper outlet is in motion while material next to the walls is stationary (stagnant). Mass flow is the ideal flow pattern where all the powder is in motion and moving downwards towards the opening. Funnel flow is where powder starts moving out through a central ''funnel'' that forms within the material, after which the powder against the walls collapse and move through the funnel. This process continues until the silo empties or until another no flow scenario occurs with the development of a stable rathole. Most flow problems are caused by a funnel flow pattern and can be cured by altering the pattern to mass flow (Johanson, 2002).

Measurement of powder flow properties is necessary for the design of mass flow hoppers. The properties that are used in the design of a mass flow hopper are the effective angle of internal friction, the material flow function, and the angle of wall friction between the powder material and the wall material. The properties to design hopper flow can be done by shear cell test.

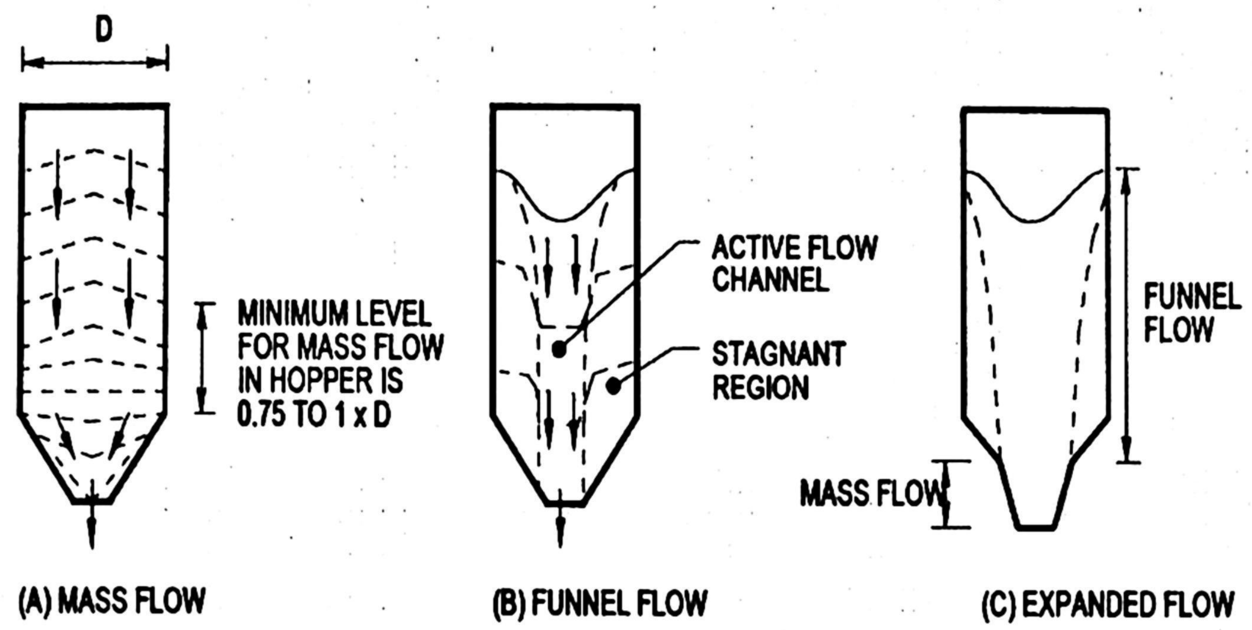

**Figure 2.2** Schematic diagram of mass, funnel and expanded flow

In mass flow (A) all material moves in the bin including near the walls. In funnel flow (B) the material moves in a central core with stagnant material near the walls. Expanded flow (C) is a combination of mass flow in the hopper exit and funnel flow in the bin above the hopper (normally used in retrofit situations).

### 2.6.1 Shear properties

Jenike pioneered the application of shear cell techniques for measuring powder flow properties (Jenike, 1964). In conjunction with the measured property data, he applied two-dimensional stress analysis in developing a mathematical methodology for determining the minimum hopper angle and hopper opening size for mass flow from conical and wedge shaped hoppers. A hopper is the lower converging section of a silo and the hopper angle is the angle between the converging section and the horizontal. The measured flow properties used in this methodology are the flow function, the effective angle of internal friction and the angle of wall friction.

The flow function is a plot of the unconfined yield stress of the powder versus major consolidating stress Figure 2.3, and represents the strength developed within a powder when consolidated, which must be overcome to make the powder flow. A flow function lying towards the bottom of the graph represents easy flow, and more difficult flow is represented as the flow functions move upwards in an anticlockwise direction. The flow index is defined as the inverse slope of the flow function. Jenike used the flow index to classify powder flowability with higher values representing easier flow. This was extended by Tomas and Schubert and is presented in Table 2.2 (Tomas and Schubert, 1979).

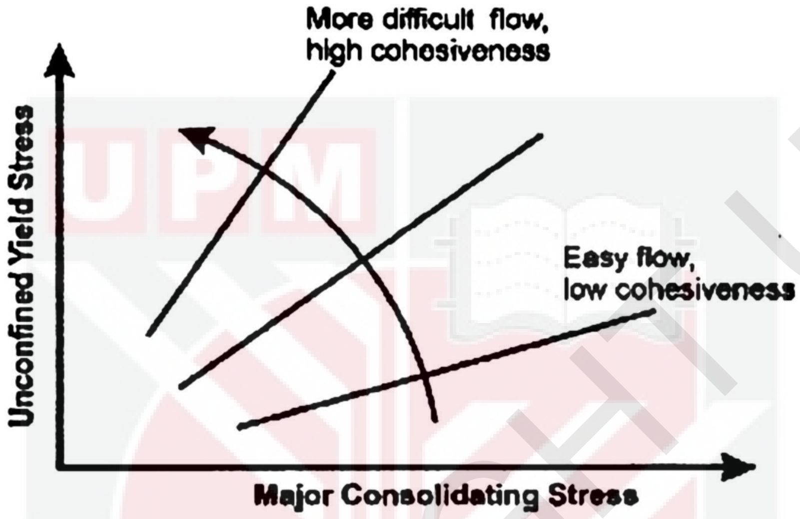

**Figure 2.3** Flow functions: Easy versus difficult flow (Fitzpatrick et al., 2004)

**Table 2.2** Jenike Classification of flowability by flow index

| Flowability | Hardened | Very Cohesive | Cohesive | Easy Flow | Free flowing |
|---|---|---|---|---|---|
| Flow Factor index, $FF_c$ | <1 | <2 | <4 | <10 | >10 |

### 2.6.2 Angle of Wall Friction, $\phi_w$

The angle of wall friction represents the adhesive strength between the powder and the silo wall material, the higher the angle the more difficult it is to move the powder along the wall surface. It is the angle between the horizontal and a straightline from the origin intersecting the measured wall yield locus (Prescott et al., 1999) as illustrated in Figure 2.4. The wall yield locus often has a positive Y -intercept, thus the angle of wall friction will vary with normal stress in the hopper, where it is higher at low stresses. The angle of wall friction has a dominant effect in determining the minimum hopper angle required for mass flow.

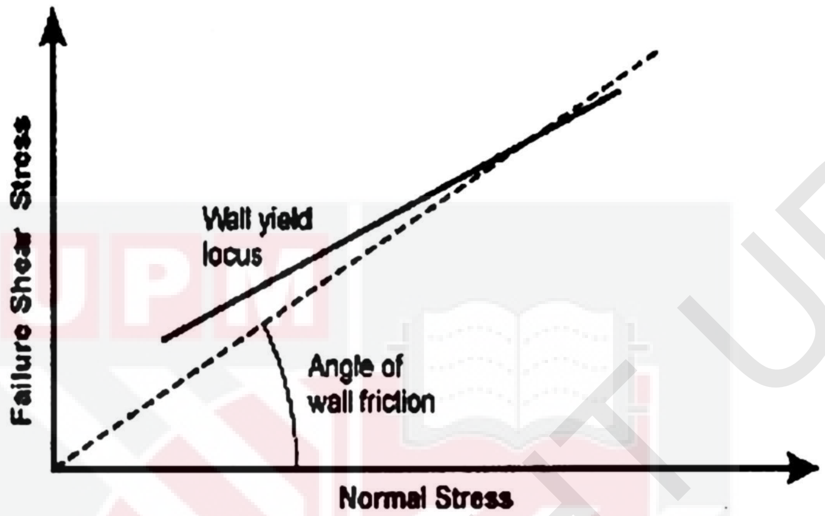

**Figure 2.4** Angle of wall friction (Fitzpatrick et al., 2004)

### 2.6.3 Critical Outlet Diameter of Hopper Flow

The most cohesive powders resulted in the greatest hopper opening requirement (Fitzpatrick et al., 2004). The minimum outlet diameter of hopper can be calculated by equation below:

$$Minimum\ outlet\ diameter, B = \frac{H(\theta)6_{crit}}{\rho_B\ g} \qquad (2.1)$$

Where *H(θ)* is a factor determined by the slope of the hopper wall, $\sigma_{crit}$ is sigma critical the intersection of flow function powder with flow factor function and g is the acceleration due to gravity. An approximate expression for *H(θ)* for conical hoppers is:

$$H(\theta) = 2.0 + \frac{\theta}{60} \qquad (2.2)$$

## 2.7 Others Factor that Influencing the Flowability of Powders

There are many factors that affect flowability of powders. The very common factor that always have been a problem toward flowabilty of powders are particle size of powder, particle shape, densities and moisture content. Here are some others factor that can affect the flowability of powder include humidity, temperature, pressure and fat content. These factors may be important measurement in designing hopper flow and packaging.

### 2.7.1 Humidity

Relative humidity of the air (interstitial as well as head space) in a storage container, such as a bin or silo, also affects bulk materials' properties. Many bulk materials are hygroscopic and thus the exposure to humid conditions results in increased moisture content of the bulk. This can lead to an increase in bulk strength (Marinelli and Carson, 1992), and also to an increase in angle of repose. Flowability of any material reduces with an increase in the angle of repose of that material. Many researchers have observed that higher humidities had significant effects on the flowability and cohesiveness of granular powders (Craik and Miller, 1958).

### 2.7.2 Temperature

Temperature also has a substantial effect on bulk solid flowability. The most drastic temperature effect is the freezing of the moisture contained within the granular materials and on particle surfaces. The resulting ice bonds weaken the flow (Irani et al., 1959). Varying the storage temperature from above freezing to 30 or 40°C does not usually have a great impact on powder flowability, if there is no melting of components or no component exceeds its glass transition temperature. But severe caking can occur whenever a granular material undergoes a change in crystallinity or other properties due to temperature variations (Johanson, 1978). Temperatures of both the wall material and the bulk material may affect the wall friction angle (Marinelli and Carson, 1992).

### 2.7.3 Pressure

Compacting pressure is also an important factor that affects the flow properties of bulk solids. The bulk may be subjected to compaction due to vibration (e.g., during transportation), impact from a falling stream of solids (e.g., during silo filling), or external loading. The effect of increased pressure on flowability of powders is twofold: (1) it leads to a larger number of contact points between particles, thus causing more inter-particle adhesion (Irani et al., 1959) and (2) the increased compaction produces a significant increase in critical arching dimensions.

### 2.7.4 Fat Content

High fat content led to worse flow of powders (Perez and Flores, 1997). The fat content in the powder can disturb the flowability of powder. This can be due to the behaviour of the powder can change when it is expose to the air and expose to the wall of hopper flow. The study of chemical composition powder should be considered in determine the flowability of powder because it also can be a major factor to determine the flowability of powder. Hence, increased fat content reduced powder flowability.

# CHAPTER 3: MATERIALS AND METHODOLOGY

## 3.1 Materials

The materials that been used in this study are flour powder. Four different type of commercial flour which is wheat flour (*Cap ros*), cornstarch flour (*Cap bintang*), tapioca flour (*Sure rasa*) and atta flour (*Krisanya*) were used in this study. These four types of flour were bought from the local supermarket that located at Sri Serdang, Selangor Malaysia. In chapter 2 have explained the type of the flour samples. Figure 3.1 show the sample of the flours.

(A) Wheat Flour (B) Cornstarch Flour (C) Tapioca Flour (D) Atta Flour

**Figure 3.1** The sample of the Flour Powders

## 3.2 Physical Properties of Flour Powders

### 3.2.1 Particle Size

The particle size and size range of the powder samples were measured by using laser light diffraction equipment, Particle Size Analyzer (Malvern Mastersizer 2000, U.K). The instrument can analyse the medium particle and size analysis. The particle size as well as size distribution at $D_{10}$, $D_{50}$ and $D_{90}$ will be determined from the equipment. For this experiment, the powder samples were placed in the particle size analyser and the data was recorded automatically. Each sample powder were triplicate to obtain the average data.

### 3.2.2 Bulk Density, $\rho_b$

The bulk density of the samples was determined manually by pouring 2.5 g of flour powder into a 100 mL graduated measuring glass cylinder. The bulk density was calculated from the ratio of the mass of powder to the volume occupied by the powder (Goula et al., 2004). The volume in the cylinder recorded without tapping. The experiment were triplicate to obtain average data. From the data obtained, bulk density, $\rho_b$ can be calculated by using the equation below:

$$\rho_b = \frac{m}{V} \qquad (3.1)$$

Where $\rho_b$ is bulk density, $m$ is mass of the powder, and $V$ is the volume of the powder determined without tapping.

### 3.2.3 Tapped Density, $\rho_t$

The tapped density of the sample was determined as the sample chamber with 25.4 mm is rotated and agitated while a precise specified force 51 kN is applied to the sample. The samples was measured by placing an approximately 2 g powder sample into the vessel of the Envelop and Tap Density Analyzer. The equipment use to determine the tapped density is envelope density analyser (GeoPyc 1365; Envelope Density Analyzer, Micromeritics, USA). The parameters was set for tapped density are the set data to analyze for 3 cycle before pressing the Run Key. The average density are obtained directly from the equipment. The data of density was recorded manually.

### 3.2.4 True Density, $\rho_s$

The true density of the sample was determined by pouring 1.5 g of flour powder in a chamber. The volume of the sample was measured using the gas displacement method. The sample weight was recorded and entered into the computer program, and the results were shown automatically after finishing the process (Saifullah et al., 2016). The equipment used to determine the true density is gas pycnometer (AccuPyc II 1340; Pycnometer Micromeritics, USA).

### 3.2.5 Porosity, $\varepsilon$

The porosity of the powder was calculated from the powder density and true of the powder. It was calculated using the following equation:

$$\varepsilon = 1 - \frac{\rho_t}{\rho_{true}} \tag{3.2}$$

Where $\varepsilon$ is the porosity, $\rho_t$ is the tapped density of the powder and $\rho_{true}$ is the true density of the powder.

### 3.2.6 Moisture Content

Moisture content (wet basis and dry basis) was measured by weighing approximately 1 g of a sample before and after drying in an oven at 105°C for 24 hours. Each test was carried out in triplicate. The wet basis and dry basis can be calculated by equation below:

$$\text{Wet basis} = \frac{M_W - M_D}{M_W} \qquad (3.3)$$

$$\text{Dry basis} = \frac{M_W - M_D}{M_D} \qquad (3.4)$$

Where $M_W$ is mass of wet sample (g) and $M_D$ is mass of dry sample (g).

## 3.3 Nutrition Facts

The Nutrition Facts provides detailed information about a food's nutrient content, such as the amount of fat, sugar, protein and fiber it has. The table 3.1 show the nutrition facts of the wheat, cornstarch, tapioca and atta flours per 100g.

**Table 3.1** The nutrition facts of the wheat, cornstarch, tapioca and atta flours per 100g.

| Powders | Carbohydrates (g) | Protein (g) | Fat (g) |
|---|---|---|---|
| Wheat | 74 | 9 | 1 |
| Cornstarch | 90.3 | 0.1 | 0.15 |
| Tapioca | 86.6 | 1.2 | 0.1 |
| Atta | 81.2 | 12.2 | 2.2 |

**Nutrition facts were taken from the packaging of each flour sample.*

## 3.4 Powder Flow Properties

### 3.4.1 Carr Index and Hausner Ratio

The Carr Index and the Hausner Ratio were used to investigate the flow property of the samples. The Carr Index and the Hausner Ratio were calculated from the bulk density and tapped density as follows:

$$CI = \frac{\rho_t - \rho_b}{\rho_t} \times 100\% \quad \text{(Carr, 1965)} \tag{3.5}$$

$$HR = \frac{\rho_t}{\rho_b} \quad \text{(Hausner, 1967)} \tag{3.6}$$

Where, CI is Carr Index, $\rho_t$ is tapped density, $\rho_b$ is bulk density and HR is Hausner Ratio. Different ranges for the Carr Index and the Hausner Ratio have been defined by Lebrũn et al. (Lebrũn et al., 2012) as presented in Table 3.2.

**Table 3.2** Flowability classification (Lebrũn et al., 2012)

| Flowability | Carr Index ($CI$) (%) | Hausner Ratio ($HR$) |
|---|---|---|
| Excellent | 0-10 | 1.00-1.11 |
| Good | 11-15 | 1.12-1.18 |
| Fair | 16-20 | 1.19-1.25 |
| Passable | 21-25 | 1.26-1.34 |
| Poor | 26-31 | 1.35-1.45 |
| Very Poor | 32-37 | 1.46-1.59 |
| Very, very Poor | >38 | >1.60 |

### 3.4.2 Caking Strength

Caking test is done by using the equipment Texture Analyzer (TA.XTplus Texture Analyzer Stable Micro Systems, London, U.K). The powder sample were inserted into the standard vessel approximately 200 ml which weighed around 100g of sample where the standard vessel will be attached to the equipment and then run the test. Before run the test, calibrate of force and height was done. The rotor moves to a force of 5 g at 20 mm/s and 2°. This step levels off the powder and allows to record the rate at which the column height reduces during the caking process. Once target force is reached, the data is recorded as it moves down through the powder column at 20mm/s and 20° until it reaches a force of 500 g. Then the rotor moves upwards at 10 mm/s and 45° subjecting powder column to minimum displacement. This is repeated for five compactions. At the end, the rotor slices through the compacted cake recording hardness of the cake, i.e. the force required to get the compacted powder flowing freely. Finally the rotor moves back to the top. The data analysis is done using the data on column height at the start of each compaction cycle, the distance at the point the final 500 g force is reached (the cake height) for each cycle, and finally the mean force and work required (g.mm) to slice through the caked area. Cake height ratios (ratio of the initial column height) and also the cake strength (both as the mean force and also the work required—the area under the curve) are calculated (Benkovic and Bauman, 2009). Finally, the result of caking strength will be obtained. Each samples were tested for three times to obtain the average data.

### 3.4.3 Cohesion

Cohesion test is done by using the equipment Texture Analyzer (TA.XTplus Texture Analyzer Stable Micro Systems, London, U.K). The powder sample were inserted into the standard vessel approximately 200 ml which weighed around 100g of sample where the standard vessel will be attached to the equipment and then run the test. The result of cohesion index were automatically obtained from software computer. Cohesion index is defined as the ratio cohesion coefficient/sample weight. Low cohesion index is associated with non-cohesive free-flowing powders. High cohesion index is associated with cohesive, poor flowing powders (Landillon et al., 2008). Powder categorization scale based on cohesion index is shown in Table 2.1. The experiment was repeated for three times to obtain average data.

### 3.4.4 Powder Flow Speed Dependency (PFSD)

Powder Speed Flow Dependency (PFSD) test is done by using the equipment Texture Analyzer (TA.XTplus Texture Analyzer Stable Micro Systems, London, U.K). The method of PFSD test is same as caking and cohesion test. The result of stability index PFSD was obtained automatically form the computer software. The experiment was repeated for three times to obtain average data.

## 3.5 Compressibility

### 3.5.1 Uniaxial Die Compaction

A commercial die compaction machine (Instron Universal Testing Machine-5566, Canton MA, UK) was used for compression Figure 3.1. The Bluehill software (Canton MA, USA) was the operating software of that particular machine, which helped to maintain a compaction speed of 0.1 mm/min at four different force settings of 4kN, 6kN, 8kN and 9kN. After reaching the maximum force set for tablet formation, the tablet was ejected from the die and the thickness of the tablet was measured by using vernier caliper to calculate the final volume and density of the powder in tablet form. The experiment was repeated for three times at every force for each sample to obtain average data.

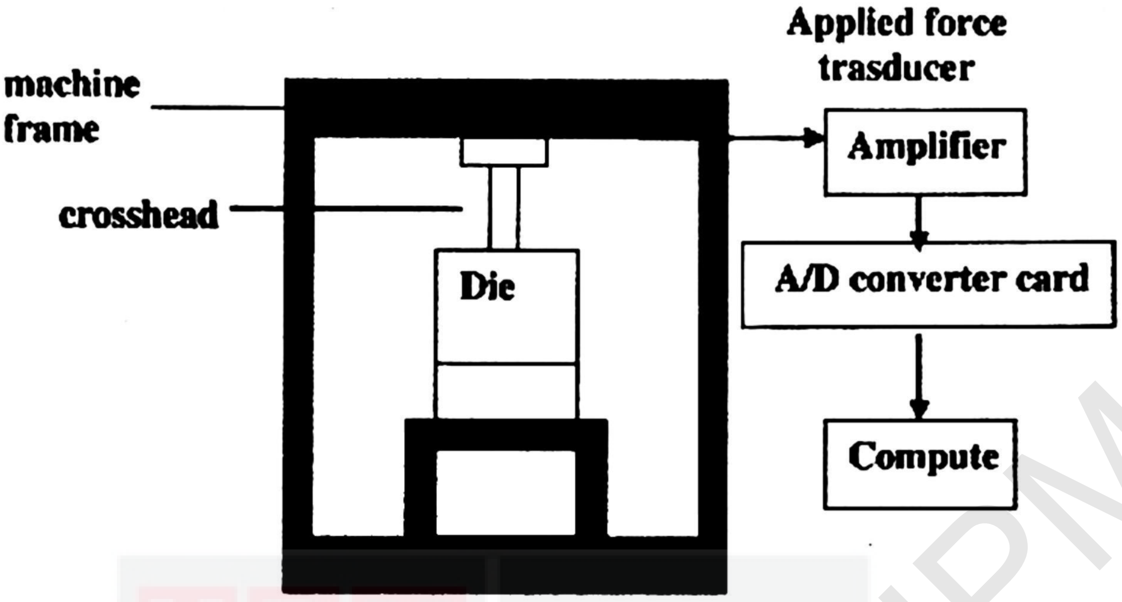

**Figure3.2** Schematic layout of the uniaxial die compaction system (Yusof et al., 2010)

### 3.6 Shear Cell Test

Shear test was used to measure the flow properties. Shear cell measurements are widely used to determine the flowability of powders related to the powder discharge. Shear Cell tests are performed on consolidated powders/flours and are intended to determine how easily a previously at rest sample can be made to move. This test is done by using Powder Flow Tester (Brookfield, USA). This process removes any packing history such as preconsolidation or excess air. As the shear cell is rotated, the force (normal stress) was kept constant and the torque (shear stress) was measured. Therefore, during shearing the shear head can displace vertically to keep the normal stress constant if the sample compresses.

The powder initially resists the movement, the shear stress was increased until this resistance is overcome and the powder bed fails or shears. This is the point where flow occurs and is known as the Yield Point or Point of incipient failure. The shear stress and normal at the point of incipient failure were recorded before the cycle is repeated at a series of lower normal stress levels. These are plotted on a graph to produce the yield locus. The line passing through the incipient failure points which are usually five points is called the yield locus and was the basis of the parameters obtained during the shear test Figure3.3. These tests were originally used to design hoppers and silos, but have become increasingly usefull for general characterization of granular materials (Freeman, 2007).

Different parameters obtained from this test were:

- Unconfined Yield Strength (UYS) (kPa)
- Major Principle Consolidating Stress (MPCS) (kPa)
- Angle of internal friction (δ) (angle created by the best fit line with the horizontal axis)
- Angle of wall friction, $\phi_w$ ( ° )
- Bulk density from shear cell, $\rho_b$ (kg/m$^3$)
- Flow function coefficient (FF or ffc) (Ratio of the major principal stress to the unconfined yield strength)

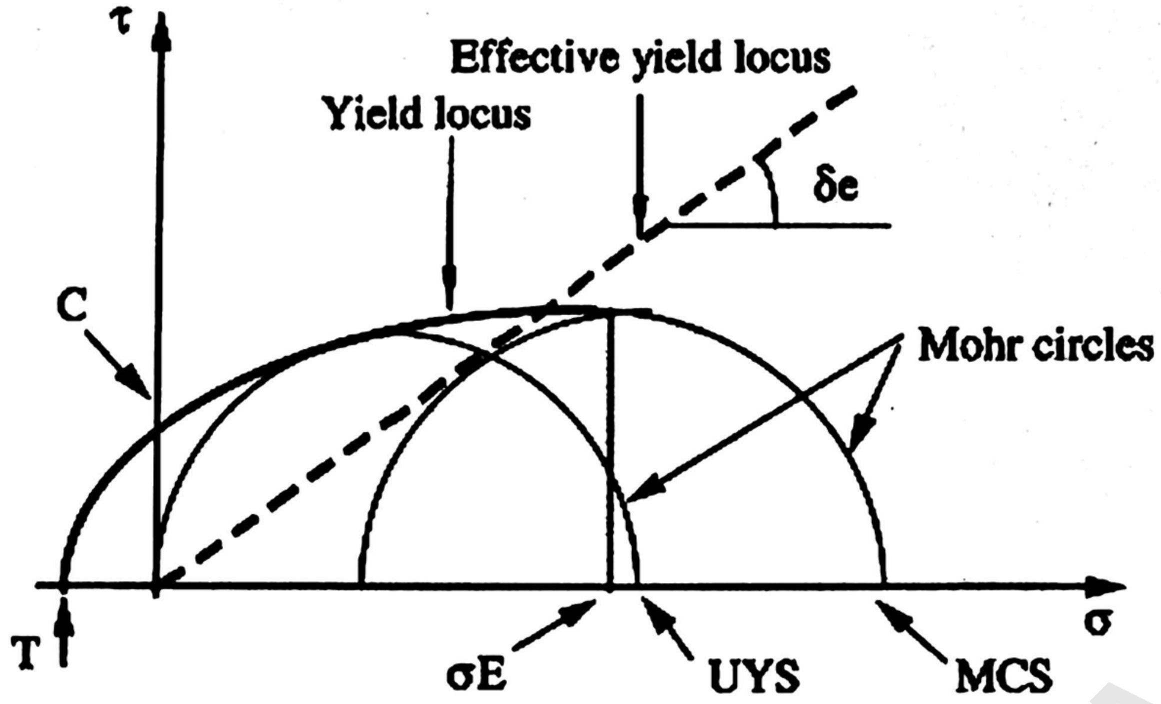

**Figure 3.3** Representative graph for shear test (Slettengren et al., 2015)

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Results and Discussion

This chapter describes the various experimental results obtained using the techniques described in chapter 3. This chapter also consists of experimental results that have been done for physical properties of the flour powders; wheat, cornstarch, tapioca and atta powders, the effect of compressibility and particle size on flowability of powders and the hopper design for the powders. The flour powders used in the present study were wheat, cornstarch, tapioca and atta flour.

## 4.2 Physical Properties of Flour Powders

The physical properties of the flour powders have a major influence on the design, optimisation and performance of food powder products. The physical properties of powder include particle size, bulk density, tapped density, true density, porosity and moisture content (wet and dry basis) and the flow properties include Carr Index, Hausner's ratio, and flowability. Table 4.1 show the physical properties of the flour powders.

Table 4.1 Physical Properties of Powders

| **Powder Properties** | | **Wheat Powder** | **Cornstarch Powder** | **Tapioca Powder** | **Atta Powder** |
|---|---|---|---|---|---|
| Particle Size (μm) | $D_{10}$ | 16.85 ± 0.61 | 8.65 ± 0.03 | 9.27 ± 0.02 | 22.38 ± 0.05 |
| | $D_{50}$ | 70. 52 ± 3.77 | 13.94 ± 0.04 | 14.34 ± 0.03 | 116.14 ± 1.11 |
| | $D_{90}$ | 140.93 ± 4.63 | 22.05 ± 0.08 | 21.88 ± 0.05 | 173.96 ± 2.12 |
| Bulk density, $\rho_b$ ($kg/m^3$) | | 510.82 ± 10.33 | 496.93 ± 5.83 | 497.07 ± 11.73 | 547.89 ± 13.28 |
| Tapped density, $\rho_t$ ($kg/m^3$) | | 878.5 ± 0.003 | 702.3 ± 0.004 | 679.2 ± 0.005 | 955.9 ± 0.006 |
| True density, $\rho_s$ ($kg/m^3$) | | 1512.9 ± 1.47 | 1558.5 ± 1.32 | 1563.2 ± 0.23 | 1496.7 ± 0.47 |
| Porosity, $\varepsilon$ | | 0.42 | 0.55 | 0.57 | 0.36 |
| Hausner Ratio, *HR* (Hausner , 1967) | | 1.72 | 1.41 | 1.37 | 1.74 |
| Car Index, *CI* (%) (Carr, 1965) | | 41.85 | 29.24 | 26.82 | 42.68 |
| Flowability | | Very, very poor | Poor | Poor | Very, very poor |
| Moisture content, Wet basis (%) | | 11.93 ± 0.31 | 10.69 ± 0.06 | 10.18 ± 0.3 | 6.54 ± 0.14 |
| Moisture content, Dry basis (%) | | 13.54 ± 0.4 | 11.97 ± 0.08 | 11.33 ± 0.37 | 7 ± 0.16 |

### 4.2.1 Particle Size Analysis

Table 4.1 represented the particle size analysis at $D_{10}$, $D_{50}$ and $D_{90}$. Results depicted that there were significant difference among flours at the average particle size ($D_{90}$). A higher number of fines (173.96 ± 2.12 μm) were found in atta flour and the lowest number of fines (21.88 ± 0.05 μm) were found in tapioca flour at the average particle size ($D_{90}$). Cornstarch and tapioca flours have similar result which were (22.05 ± 0.08 μm) and (21.88 ± 0.05 μm) respectively at the average particle size ($D_{90}$). At first, the average particle size ($D_{10}$) of food flours was not significantly different between the flour powders. However, the average particle size start significantly varied at ($D_{50}$) between the flours. Based on the classification of British Pharmacopoeia (Barbosa et al., 2005), flour powder can be classified as a fine powder type essentially all the particles have sizes >0.180mm. The wheat, cornstarch, tapioca and atta can be considered as fine powders. Reduction in particle size often tends to decrease the flowability of a given granular material due to the increased surface area per unit mass (Fitzpatrick et al., 2004). The smaller the particle size the flowability of powders will decrease.

However in this study the atta and wheat flours have the poorest flowability even their particle size is larger than cornstarch and tapioca flours. This is because the chemical composition of atta and wheat itself. Wheat and atta flours contain higher fat content compared to cornstarch and tapioca flour. High fat content led to worse flow of powders (Perez and Flores, 1997). Table 3.2 show the nutrition facts of wheat, cornstarch, tapioca and atta flours. The atta flour contain the highest fact content whereas tapioca flour contain the lowest fat content. The higher the fat content the flowability of powder will decrease. Fat content will cause the powder to cake and the cohesion of the powder will increase. It will result poor flowability. This proven when

Carr Index and Hausner Ratio indicated that wheat and atta flours were very, very poor flowability. Atta and wheat were very cohesive powders that affected by chemical composition characteristics than particle size. Thus, the flowability of the powders also can be influenced by the composition of fat content of the flour powders instead of particle size.

### 4.2.2 Bulk, Tapped and True density

In order to select the most appropriate storage, processing, packaging and distribution conditions, it is essential to measure the bulk density of a food powder (Barbosa et al., 2005). Table 4.1 shown that the highest bulk density were found in atta (547.89 ± 13.28 kg/m$^3$) followed by wheat, tapioca and cornstarch flour powder. The results show that the larger particle size have a greater bulk density. High bulk density will result for poor handling and transportation of powders. Increasing bulk density of powders also indicate to poor flowability. Attta and wheat flours have high bulk density that indicate to poor flowability followed by cornstarch and tapioca flours. The highest tapped density was found in atta powder (955.9 ± 0.006 kg/m$^3$) whereas the lowest tapped density was found in tapioca (679.2 ±0.005 kg/m$^3$). True density have quite similar result between wheat, cornstarch and tapioca powder except for atta which was show a lowest value of true density. Since the densities of flour powders depend on the combined effects of moisture content, particle size and inter-particle cohesion force, therefore any variation in specific characteristics may result in a significant change in the bulk, tapped and true density of flour powders (Johanson, 1978). Atta have the highest densities except for true density compare to the others.

### 4.2.3 Moisture Content of Flour Powders

Table 4.1 represents the moisture content of wet and dry basis of the different types of flour powders. The moisture content of the samples varies from one sample to another. The wheat powder contains the highest moisture content at (11.93 ± 0.31 %) and the atta powder contains the lowest moisture content at (6.54 ± 0.14 %) of wet basis. The dry basis of moisture content also give a same result as wet basis which were wheat powder give (13.54 ± 0.4 %) and atta powder (7 ± 0.16 %). This is shown that wheat powder had the highest moisture content whereas the atta powder had the lowest moisture content. The moisture content has a significant influence on the physical sate and reconstitution rate of powdered foodstuff (Quek et al., 2007). Moisture content can affect the cohesive strength and arching ability of bulk materials (Johanson, 1978). As the moisture content of a powder increases, the adhesion (Craik and Miller, 1958) and cohesion (Moreyra and Peleg, 1981) tend to increase. Hence, the flowability decreased with increase in moisture content (Ganesan et al., 2008). One of the reasons of increasing moisture content of any powder product could be the hygroscopic of powder which facilitates in the ability of powders to absorb moisture easily from the air (Juarez et al., 2017). This shows that wheat flour has higher ability to absorb moisture content from the air compared to the others flour that causes the flowability of the flour was very poor with affected by the others factor also.

## 4.3 Caking, Cohesion and Powder Flow Speed Dependency (PFSD) properties of flour powders

The caking, cohesion and powder speed flow dependency (PFSD) also play a significant roles toward flowability of flour powders. Caking and stickiness are common problems that almost powders encounters.

### 4.3.1 Caking Properties of Flour Powders

Figure 4.1 shows the caking strength of wheat, cornstarch, tapioca and atta flour powders. Results depicted that there were a significant difference among the flours. Atta had the highest value of caking strength whereas wheat, cornstrach and tapioca had a similar result. The inter-particle bonding increase with caking. It will cause more energy to rotate the blade. It will result for poor flowability. Caking can cause by humidity or moisture absorption and increases the bulk density of sample will cause the basic flow energy increases (Jan et al., 2017). High basic flow energy will result higher energy required to flow the atta flour compared to the others flour. Fat content of atta flour also make the caking strength higher compare to the others flour. Atta flour contains high values of fat content that increasing the value of caking strength. Thus, it can be concluded that particles of atta flour have a highest bulk density that will cause the basic flow energy increases and highest value of caking strength that result to poor flowability. This can be supported when Carr Index and Hausner Ratio shows the flowabity of atta flour was very poor.

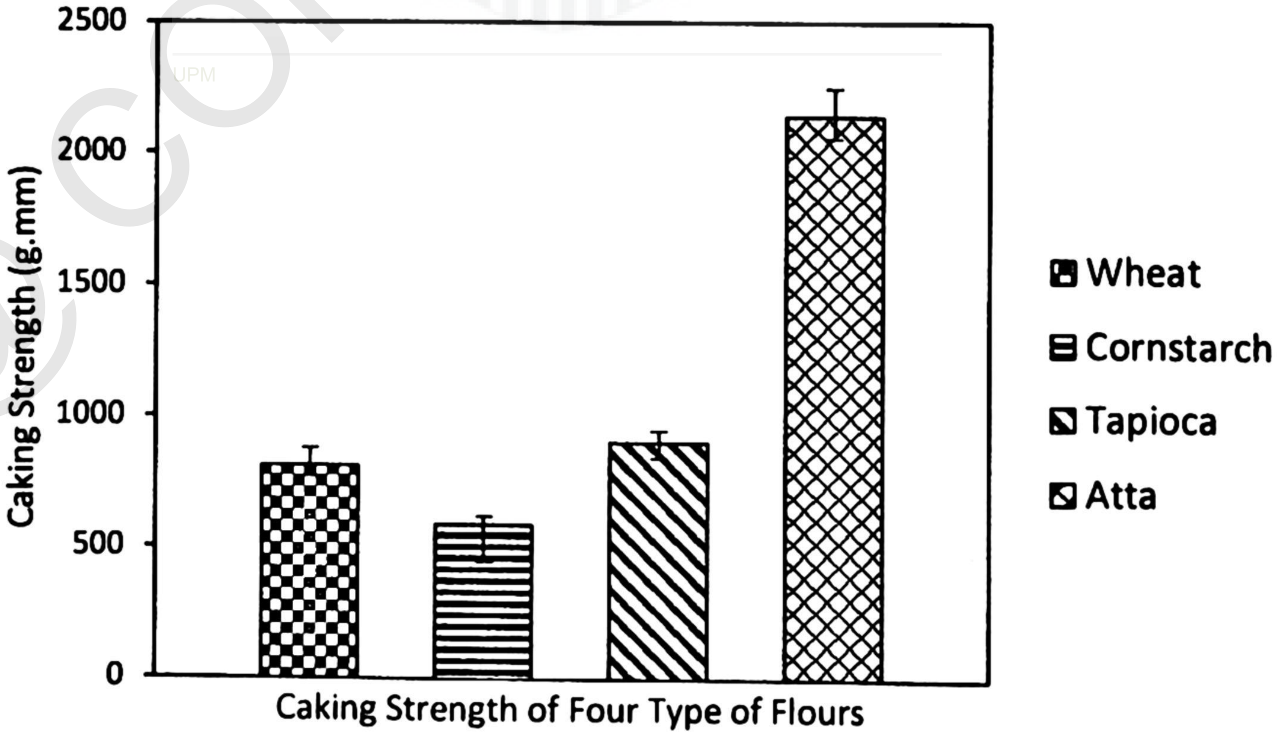

**Figure 4.1** Graph caking strength of Wheat, Cornstarch, Tapioca and Atta Flours

### 4.3.2 Cohesion Properties of Flour Powders

Figure 4.2 shows that the cohesion index of wheat, cornstarch, tapioca and atta flour powders. From the result obtained, atta flour had highest cohesion index compared to wheat, cornstarch and tapioca. Cornstarch and tapioca flours had less cohesion index compared to wheat flour. Cohesion is the sticking together of particles of the same substance. Inter-particle forces (both frictional and adhesive) are usually referred to as ''cohesion''. Cohesion is an important parameter affecting powder flow (Portillo et al., 2010). The more cohesiveness of the flours the decreases the flowability of flours. A low cohesion index is associated with non-cohesive free-flowing powders, while a high cohesion index is associated with cohesive, poorly flowing powders, as shown in Table 2.1 (Abdullah et al., 2010). The flow behaviour of atta, wheat, cornstarch and tapioca flours were extremely cohesive based on cohesion index in Table 2.1.

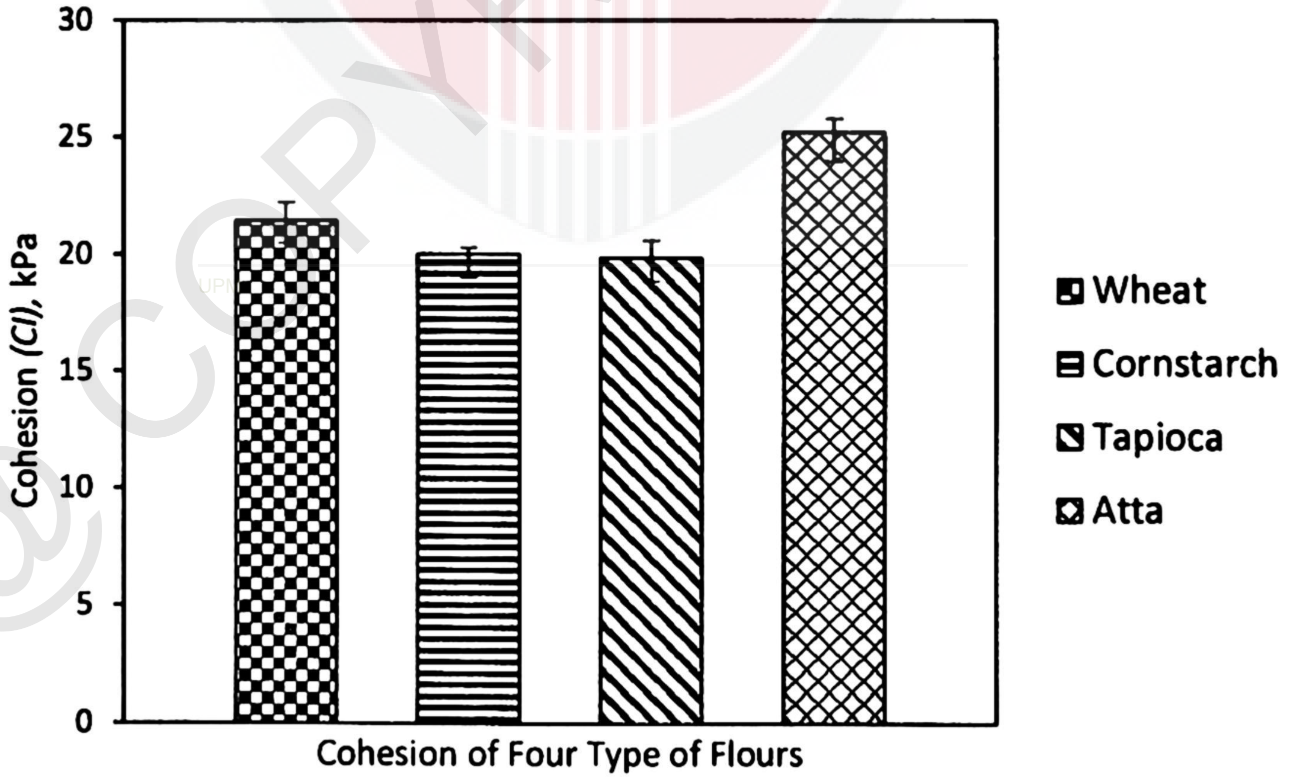

**Figure 4.2** Graph cohesion of Wheat, Cornstarch, Tapioca and Atta Flours

### 4.3.3 Powder Flow Speed Dependency Properties (PFSD) of Flour Powders

Figure 4.3 shows the powder flow speed dependency (PFSD) of wheat, cornstarch, tapioca and atta flours. The results depicted the stability index of wheat, cornstarch, tapioca and atta flours were >1. Atta flour had the highest value of flow stability index. The stability index of cornstarch flour was less than atta flour. The lowest value of flow stability index were found in wheat and tapioca flours. The stability index >1 means the product has changed during testing (giving a higher compaction coefficient), if <1 means it has changed giving it a lower compaction coefficient (Shah et al., 2008). These changes may be due to attrition of the powder particles themselves or the breaking down of agglomerates.

An increase in the compaction coefficient as the test speed increases indicates increasing resistance to flow and therefore flow speed. A decrease in the compaction coefficient with increasing flow speed would mean that the powder becomes freer flowing with increasing flow speeds dependence (Benkovic and Bauman, 2009). Wheat, cornstarch, tapioca and atta flours had a high compaction coefficient because the stability index > 1 that will cause the resistance to flow increase. When the resistance to flow increase the flowability of powders will decrease. Thus, the flowability of flours were poor. Carr index and Hausner ratio also shown the flours had poor flowability in Table 4.1.

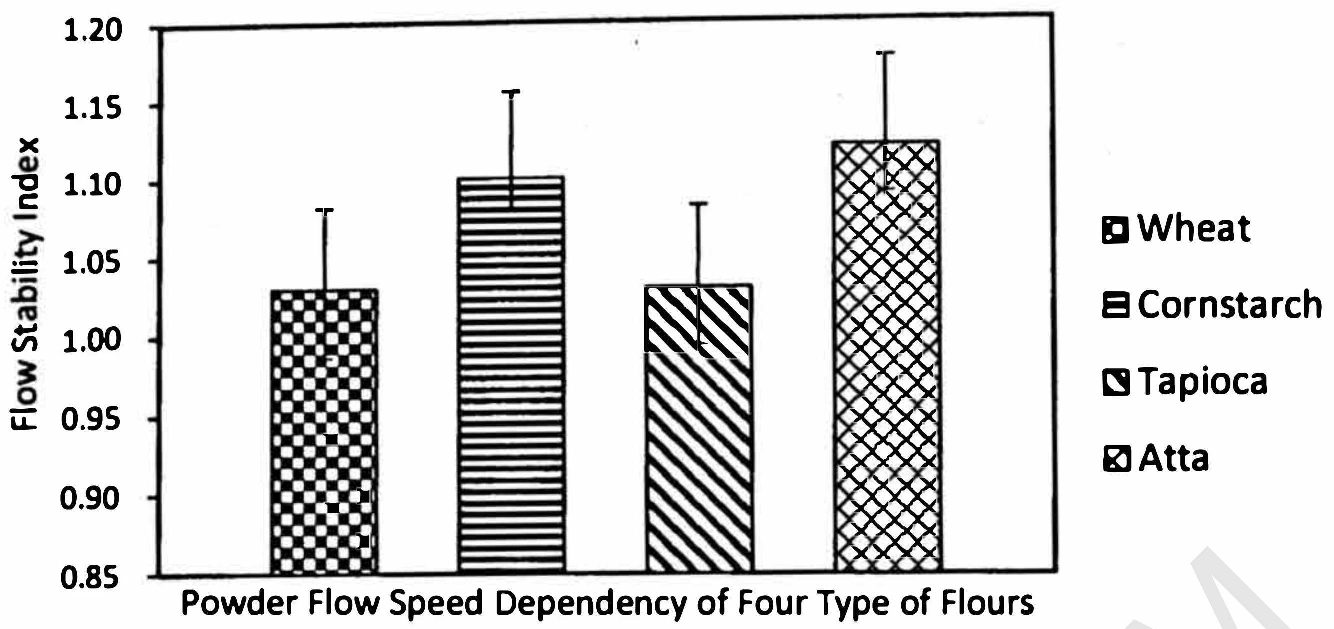

**Figure 4.3** Graph Powder Flow Speed Dependency of Wheat, Cornstarch, Tapioca and Atta Flours

## 4.4 Compressibility

### 4.4.1 Applied Pressure Volume Relationship

Figure 4.4 shows the pressure versus volume at 0.5g of wheat, cornstarch, tapioca and atta flours compressed at 4, 6, 8 and 9 kPa. The results depicted that as the applied pressure increased, the volume of the compact decreased for all the powders used. When the powders were compressed at 4 kPa, the volume of the compacts were ($447.74 \times 10^{-9}$ $m^3$) for wheat flour, ($524.03 \times 10^{-9}$ $m^3$) for cornstarch flour, ($524.03 \times 10^{-9}$ $m^3$) for tapioca flour and ($477.59 \times 10^{-9}$ $m^3$) for atta flour. The variation of the compacts' volume may be related to the flowability characteristic of the powders, which may be classified from the Hausner Ratio and Carr Index Table 3.1. Wheat flour had very cohesive flowability, its small particle size accommodated greater inter-particle friction, consequently requiring large amount of energy to overcome the inter-particle friction. Moisture content also play role in compressibility. Wheat flour had highest moisture content compared to conrstarch, tapioca and atta flours that make wheat flour can easy to be compressed. Even though, atta flour also had very cohesive flowability, but atta flour had the lowest compactability characteristics due to its large particle size and contains high fat content. Cornstach and tapioca flours were cohesive flowbility and had been characterised as difficult to flow, had the greatest inter-particle friction, and therefore, the greatest amount of energy was required to overcome this friction (Yusof et al., 2010).

At 8 kPa, the cornstarch, tapioca and atta flours volume coincided with each other. However, at higher applied pressure, the tapioca flour started to reduce in volume greater than the cornstarch and atta flours. The volume variation between cornstarch, tapioca and atta flours were relatively small. This can be considered as an intermediate process where the particle undergo sliding and rearrangement to fill void spaces. The volume variation of wheat flour was significant different compared to the other flours. Particle size and shape have considerable impact on the compressibility and is considered as an important parameter for bulk handling. Though it is not a direct measure of flowability but can be used for predicting whether the flour/powder is free flowing or cohesive. High compressibility is often associated with high cohesivity of the powders in addition to other factors such as bulk density and packing structure.

Wheat flour had smallest volume at every pressure applied. Wheat flour showed the best compressibility and highest compactability characteristics compare to cornstarch, tapioca and atta flours. Table 4.1 shows Carr index and Hausner Ratio of wheat and atta flours were very, very poor flowability whereas cornstarch and tapioca flours having poor flowability. It shown that wheat flour had high compressibility with very, very poor flowability.

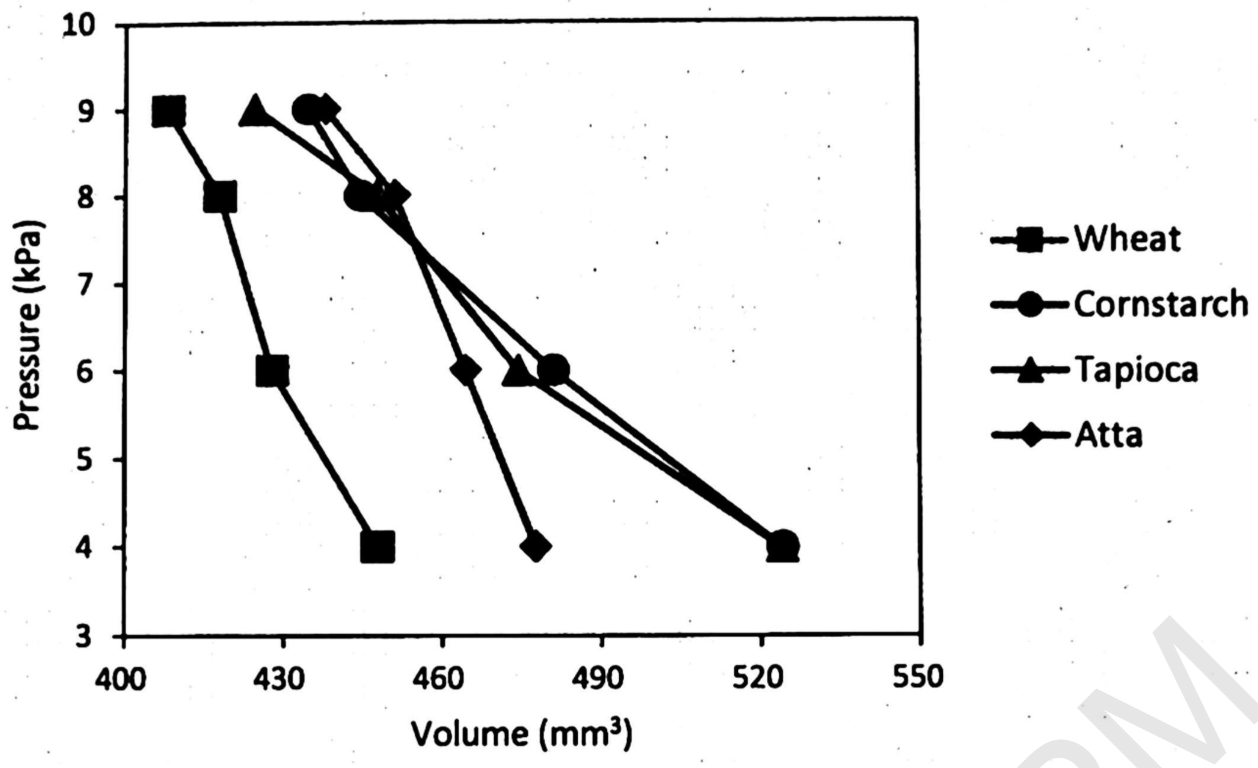

**Figure 4.4** Graph pressure-volume of Wheat, Cornstarch, Tapioca and Atta Flours

### 4.5 Shear Properties of Flours

The shear properties for wheat, cornstarch, tapioca and atta flours are presented in Table 4.2. The shear properties were obtained by shear cell test. Shear cell measurements are used to determine the flowability of powders related to the powder discharge.

**Table 4.2** Shear Properties of Wheat, Cornstarch, Tapioca and Atta Flours

| Powders | Flow factor index, $ff_c$ | Effective angle of internal friction, $\delta$ ( ° ) | Angle of wall friction, $\phi_w$ ( ° ) | Hopper angle, $\theta$ ( ° ) | Bulk density from shear cell, $\rho_b$ (kg/m$^3$) | Minimum outlet diameter, B (m) |
|---|---|---|---|---|---|---|
| Wheat Powder | 1.93 ± 0.4 (Very Cohesive) | 41.07 ± 8.59 | 21.49 | 28.5 | 592.49 ± 75.29 | 0.19 |
| Cornstarch Powder | 2.49 ± 0.98 (Cohesive) | 38.02 ± 6 | 25.21 | 23.5 | 521.37 ± 59.95 | 0.17 |
| Tapioca Powder | 2.76 ± 0.83 (Cohesive) | 36.66 ± 3.27 | 24.65 | 25.2 | 539.02 ± 61.98 | 0.15 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Atta Powder | 1.86 ± 0.58 (Very Cohesive) | 41.93 ± 8.54 | 15.26 | 33.20 | 618.16 ± 91.88 | 0.24 |

### 4.5.1 Flow Function Properties

The unconfined yield strength (UYS) versus the major principle consolidating stress (MPCS) is shown in Figure 4.5. According to the classification given by Jenike all the flours come under the category of cohesive (Jenike, 1964). However, the flowability of atta and wheat flours were found poorer than cornstarch and tapioca flours. The cohesiveness of atta flour might be due to a number of factors including its caking strength, cohesion, flow stability index and high fat content. The cohesiveness of wheat flour might be due to a higher moisture content and high fat content. Flowability of the powders was influenced by the major principal consolidating stress (MPCS) applied, which means that powders would be expected to have different flow behaviour in different regions of a hopper and at different fill heights therein (Crowley et al., 2014). It is observed that the values of UYS significantly increased with the increase of MPCS. At first the curve of wheat and atta flours were lie on very cohesive region but when MPCS increase the curve of wheat and atta were lie on cohesive region. The cornstarch and tapioca flours curve were lie on cohesive region from beginning till the end.

As previously outlined, flowability tends to decrease with a reduction in particle size. However, in this study atta and wheat powders had large particle size but low value of flow factor index which indicate their flowability very cohesive. This might be due the fat content of wheat and atta powders. In fact, even though atta flour had the highest particle size followed by wheat flour, it were also the most cohesive powder, meaning that some factor other than particle size was dominant in influencing flowability. The Car Index and Hausner Ratio were also shown that flowability of atta and wheat flours were more cohesive compared to cornstarch and tapioca flours. The lowest flow factor index was found in atta flour which means atta flour was the most cohesive powder because atta flour contains high fat content and larger particle size compare to wheat flour.

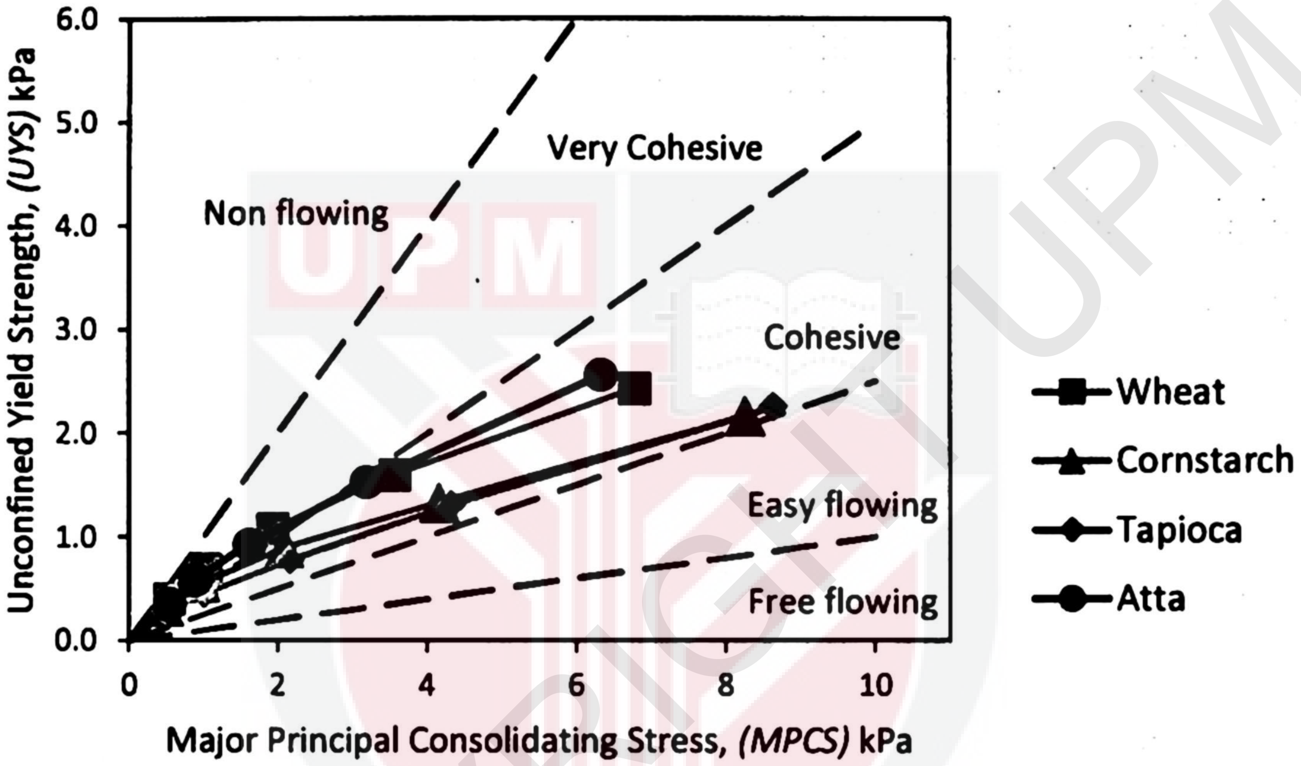

**Figure 4.5** Graph of powder flow function

### 4.5.2 Angle of Wall Friction, $\phi_w$

Table 4.2 represents the angle of wall friction, $\phi_w$. From the shear cell test the lowest angle of wall friction was found in atta flour (15.26°) and the highest value angle of wall friction was found in cornstarch flour (25.21°). Angle of wall friction of each flour were decrease when the stress applied increased. The angle of wall friction represents adhesive strength between the powder and silo wall material, the higher the angle the more difficult it is to move the powder along the wall surface (Fitzpatrick et al., 2004). This proven that atta flour had the most cohesive flowability because it had lowest angle of wall friction. This properties also useful to design the hopper flow.

## 4.6 Hopper Design

Figure 4.6 illustrates the unconfined yield strength (UYS) and major principle consolidating stress (MPCS) of wheat flour. This graph is to determine the critical stress of the wheat flour in order to calculate the minimum outlet diameter of hopper. The intersection between the powder flow function of wheat flour and flow factor line is critical stress. For the cornstarch, tapioca and atta flours the graph are shown in appendix Figure A.3, Figure A.4 and Figure A.5 with the same method of wheat flour respectively. The calculation of minimum outlet diameter of hopper is calculated. The results are presented for each powder in Table 4.2. As one might expect, the most cohesive powders resulted in the greatest hopper opening requirement (Fitzpatrick et al., 2004). This is proved when atta flour, the most cohesive powder had the largest minimum outlet diameter of the hopper (0.24 m) whereas wheat flour had the second largest minimum outlet diameter (0.19 m). Tapioca had the lowest minimum outlet diameter of hopper due to its flowability better that cornstarch, wheat and atta flours. The hopper angle shown when the minimum outlet diameter of powders decrease the hopper angle of powders increase due to their flowability.

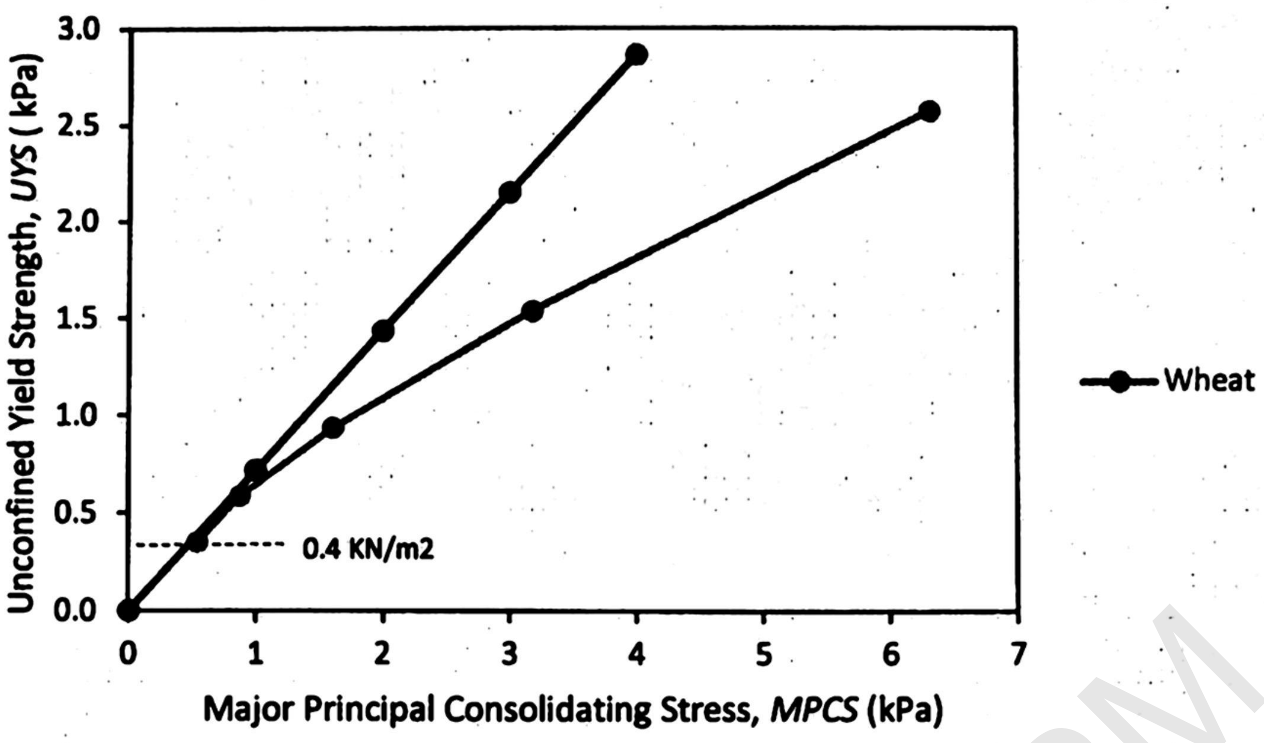

**Figure 4.6** Determination critical stress of wheat flour

# CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

The objective of the present study were to study the relationship between powder flowability and physical properties of powder and to calculate the estimation of minimum outlet diameter of hopper flow. Powder flowability was quantified using various techniques such as powder flow analyser test, density measurements, uniaxial die compaction test and shear cell test. The powder physical and chemical properties measured included the mean particle size, densities, compressibility and moisture content. Finally the influence of powder physical properties on powder flowability was studied and relate to design hopper flow.

Wheat, cornstarch, tapioca and atta flours were cohesive flowability. However, the flowability of atta and wheat flours were more cohesive compared to cornstarch and tapioca. This is because the fat content in atta and wheat flours were higher than cornstarch and tapioca flours. This can be supported when Carr Index and Hausner Ratio shown that the cornstarch and tapioca flours had poor flowability whereas atta and wheat flours had very, very poor flowability. The result from shear cell test also indicated the same result when the flow factor index of atta and wheat flours were lower than cornstarch and tapioca flours. The lower the flow factor index shown the flowability powder hardened. However, atta was more cohesive than wheat flour because atta had largest particle size with high fat content. As for the hopper flow design atta flour had the largest outlet diameter of hopper flow and the lowest outlet diameter was found in tapioca flour because the most cohesive powders resulted in the greatest hopper opening requirement.

In conclusion, atta flour was the most cohesive powder between wheat, cornstarch and tapioca flour. Atta flour had the highest value of carr index, hausner ratio and lowest flow factor index that indicated its flowability was the poorest. Atta flour had the largest outlet diameter of hopper flow because its flowability. The best flowability among the flour was tapioca flour.

## 5.2 Recommendations

This project has clearly identified the need for further experimental work to confirm the effect of each particle parameter to the resulting powder flowability. In present study the particle shape measurement does not included in the study. This properties should include to determine the flowability. Then, it would be much clearer to compare the effect of particular particle property on powder flowability.

As for the future works and recommendations, in-depth research should be carried out on various foods or flour powders such as powder flowability analysis based on their fat content and viscosity. Fat content was found to have an effect on powder flowability. It would be much clearer to compare the flowability of powder. Decreased viscosity will increase the molecular mobility and favor inter-particle interaction, hence leading to increased cohesion, formation of lumps and decreased flowability of the powder.

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# APPENDICES

**APPENDIX A:** Result From Shear Cell Test

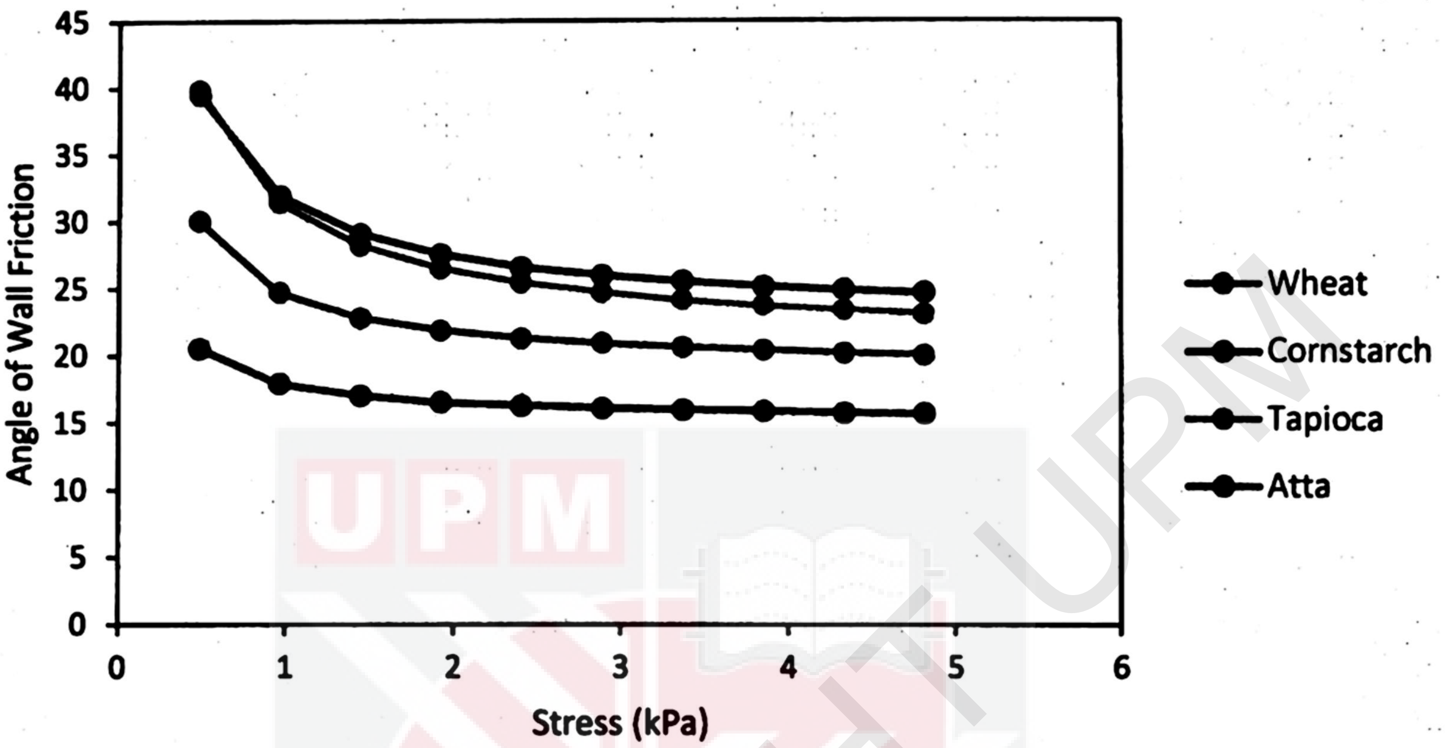

**Figure A.1** Angle of wall friction at 0 mm displacement of Wheat, Cornstarch, Tapioca and Atta Flours

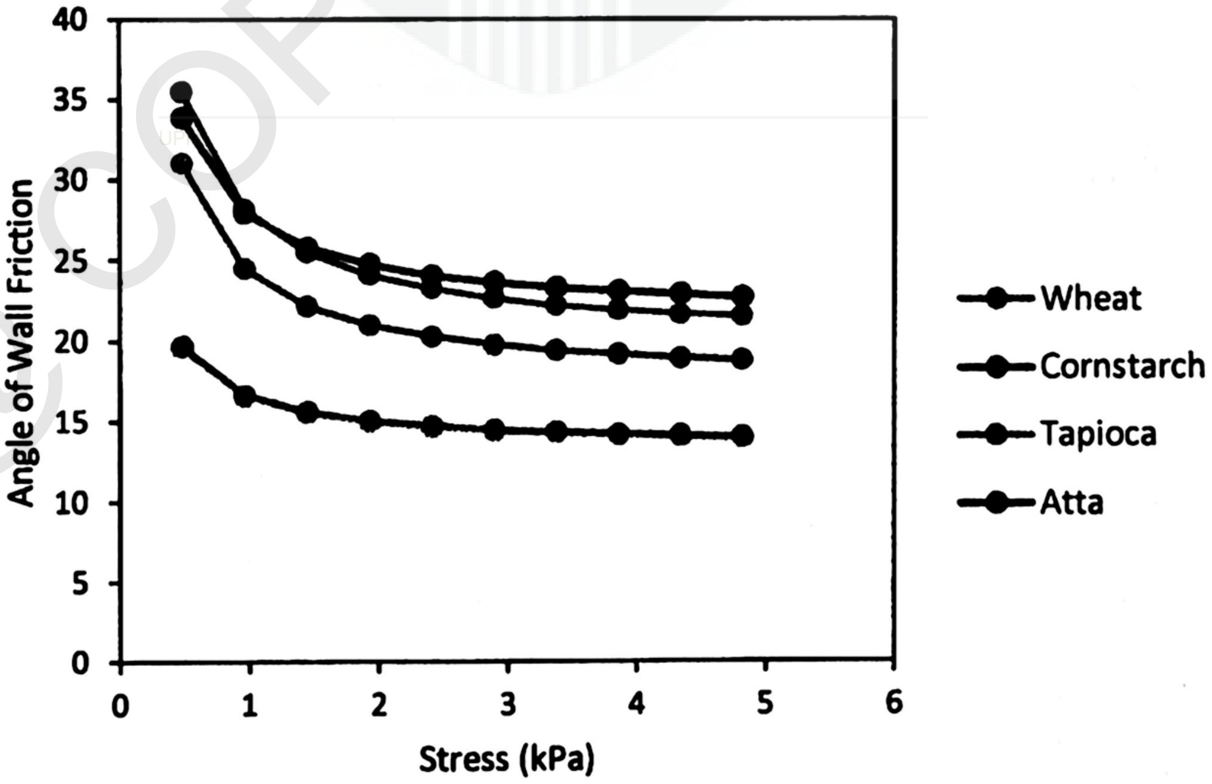

**Figure A.2** Angle of wall friction at 6 mm displacement of Wheat, Cornstarch, Tapioca and Atta Flours

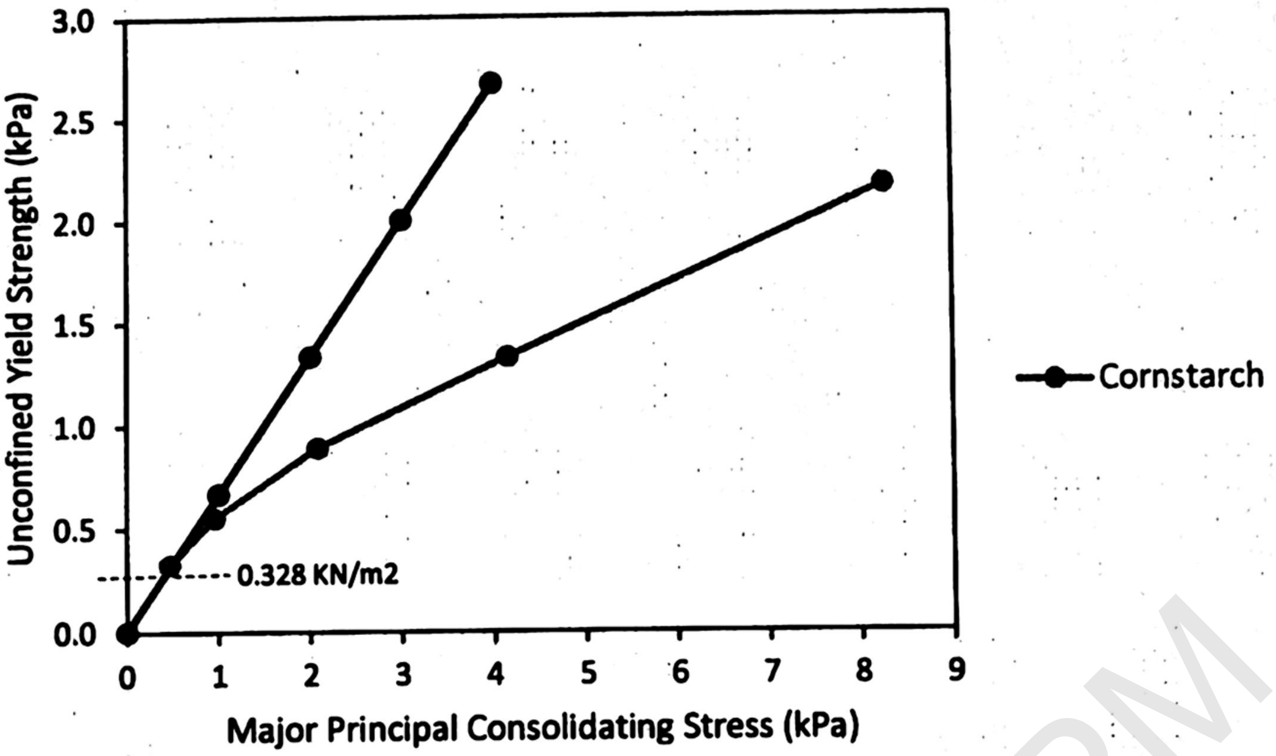

**Figure A.3** Graph of determination critical stress Cornstarch flour

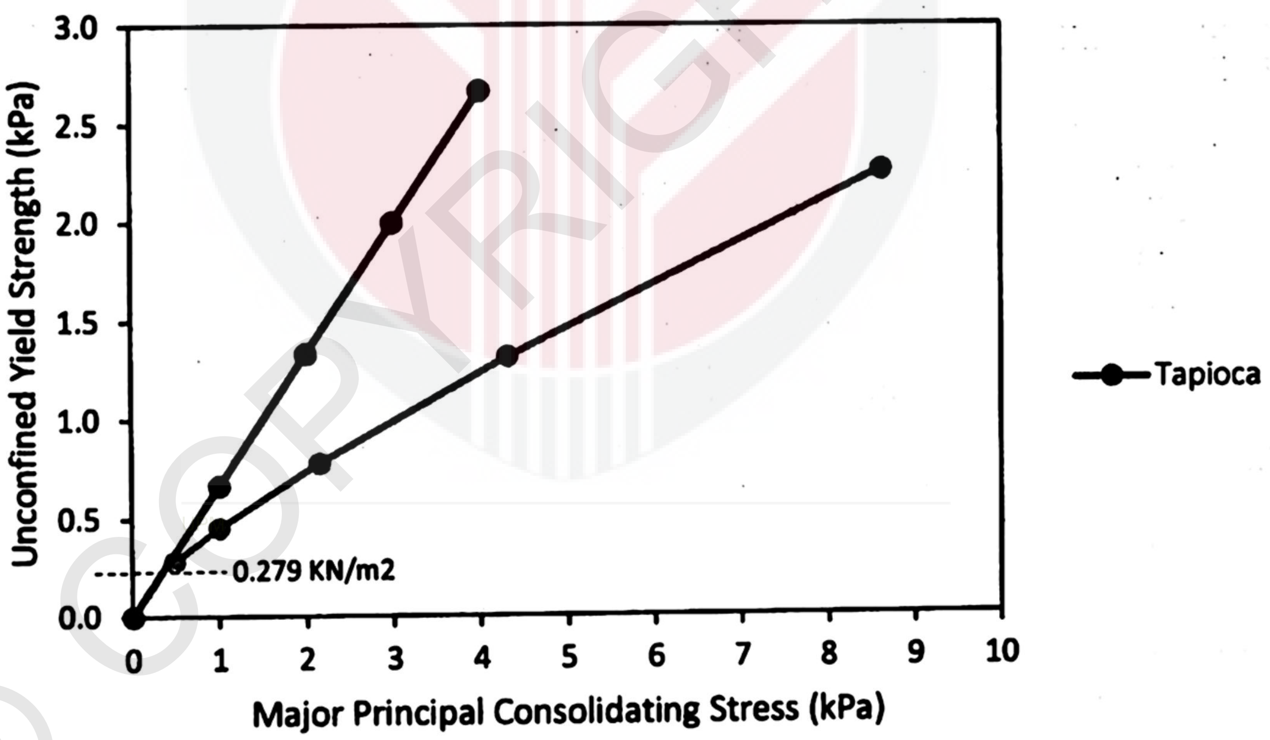

**Figure A.4** Graph of determination critical stress Tapioca flour

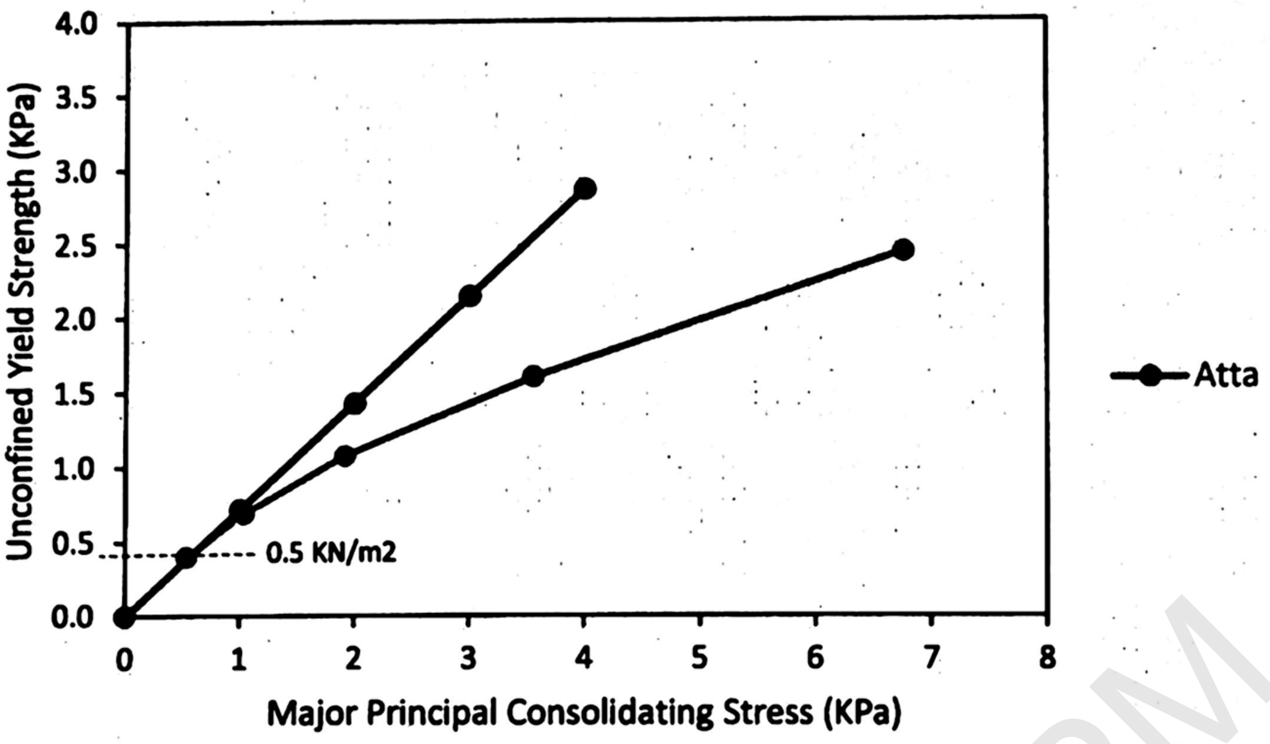

Figure A.5 Graph of determination critical stress Atta flour

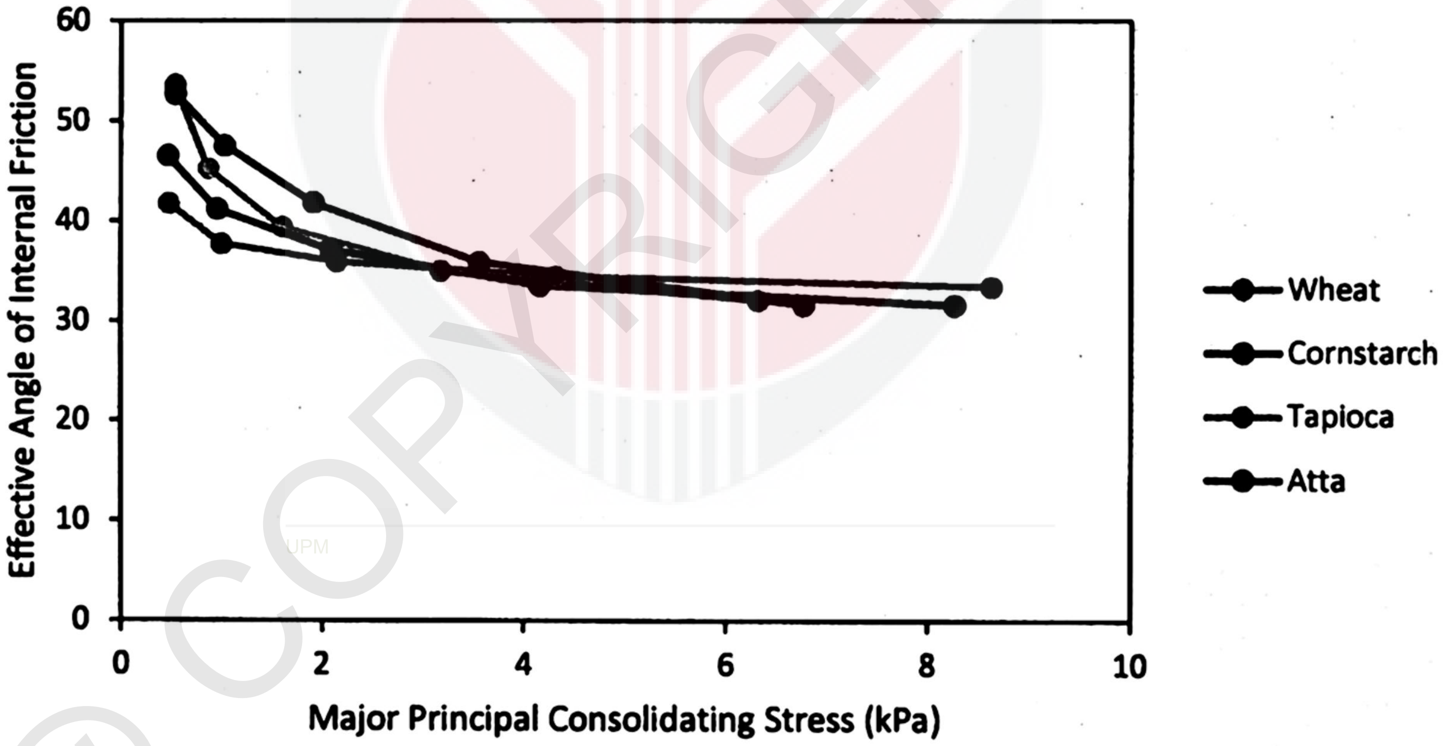

Figure A.6 Effective Angle of Wheat, Cornstarch, Tapioca and Atta Flours