UNIAXIAL DIE COMPACTION OF FOOD POWDERS

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Yus Aniza Yusof[1], Andrew C. Smith[2] and Brian J. Briscoe[3]
[1]*Department of Process and Food Engineering,*
Faculty of Engineering, Universiti Putra Malaysia,
43400 UPM, Serdang, Selangor.
[2]*Institute of Food Research, Norwich Research Park,*
Colney, Norwich NR4 7UA, UK.
[3]*Department of Chemical Engineering and Chemical Technology,*
Imperial College London, London SW7 2AZ, UK.
E-mail: [1]niza@eng.upm.edu.my

ABSTRACT

This paper presents a study of uniaxial die compaction of food powders for typical food powders such as maize powder and maize grits as well as a universal binder known as microcrystalline cellulose or Avicel. This method of compaction is widely applied in the industry as it can investigate the compressibility and compactability characteristics of powders prior to handling, storage, packaging, and transportation. In the current context, a cylindrical uniaxial die of 20 mm was used to compress the powders into compact. Pressures ranging of 30 and 160 MPa were applied to the uniaxial die using a universal testing machine. It was found that Avicel powder showed the highest compactability characteristic, ability to form bonding easily. Whereas, compactability of both the coarse maize and fine maize were quite similar, which may be due to the similar chemical composition. The data were then validated using an established compression equation. The asymptotic residual modulus value reduced as the ability of the food powders to form plastic junctions - assuming that they existed - increased. For the tensile strength test, Avicel compact showed the greatest tensile strength, many times that of fine maize and coarse maize compacts. However, between the fine maize and coarse maize, fine maize had higher tensile strength which may be due to its smaller particle size, as well as the fact that the contact area may be increased, and consequently may form a more coherent compact. The results indicate that this simple approach can be used to understand the compressibility and compactability characteristics of food powders which are essential for engineering and technology application.

Keywords: *Compactability, Compressibility, Food Powders, Stress Relaxation, Tensile Strength, Uniaxial Die Compaction*

1.0 INTRODUCTION

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 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.

The uniaxial die compaction test may be carried out on various types of materials, including food and the texture of food products [1, 2, 3]. Subsequently, many researchers used this technique to evaluate the mechanical properties of such materials. For instance, the uniaxial die compaction method was used to investigate the physical properties of food powders such as baby milk formula, coffee creamer, commercial sucrose and common salt [4].

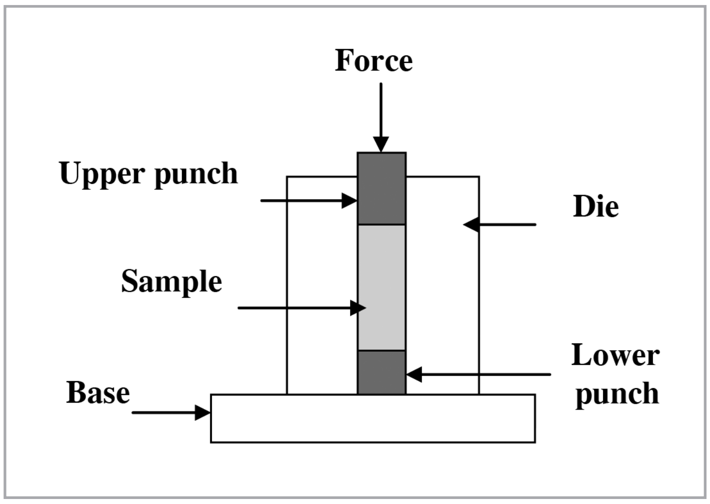

Figure 1: A schematic diagramme of uniaxial die compaction

1.1 Applied Pressure-Volume Relationship

The applied pressure-volume relationship from the uniaxial die compaction is used for the analysis of the interactions between the particles and the particles as well as the particles and the wall, and the study of the microstructure of compact. There are many equations available to describe the powder compaction processes which have been put forward by several researchers, including; Heckel [5], Cooper and Eaton [6], Kawakita and Lüdde [7] and others. Among these equations, the Kawakita and Lüdde [7] equation is probably the most widely used model in both the powder metallurgy and the pharmaceutical industries particularly for soft medical powders, and is used exclusively in the current study. The Kawakita and Lüdde [7] equation in the linear inter-relationship is:

$$\frac{\sigma_a}{C} = \frac{1}{ab} + \frac{\sigma_a}{a} \tag{1}$$

where σ_a is the applied pressure, C is the degree of volume reduction (defined as $C = (V_o\text{-}V)/V_o$, with V_o is the powder volume before pressure is applied, and V is the powder volume under applied pressure), and a and b are the constants characteristics of the powder. The constant value a has been considered as representing the initial porosity in the case of piston compression. The value of the constant b has been related to the resisting force, or the cohesiveness, of powdery particles in the case of tapping and vibrating.

The main characteristics to be investigated by unixial die compaction are presented in the form of applied pressure-volume relationships, compressibility factor, stress relaxation, and tensile strength. The applied pressure-volume relationship is further analysed by fitting the Kawakita and Lüdde [7] equation. Therefore, qualitative studies of the porosity and cohesiveness may be obtained. The compressibility factor is calculated from the plot of the applied pressure-volume relationship at the high-applied pressure region [8]. While, the extent of the stress relaxation of the powder is characterised by a stress relaxation modulus, also known as the asymptotic residual modulus, which was developed by Peleg and Moreyra [9]. The tensile strength of the powder is investigated by a diametrical compression test [10], an indirect tensile test that has been particularly used for powders.

2.0 EXPERIMENTAL PROCEDURES

2.1 Food Powder Properties

A number of particulate food powders were used in the current study such as maize powder and maize grits (F. Smiths Mills Worksop, UK) and microcrystalline cellulose or Avicel (FMC, USA), and their material properties are shown in Table 1. A laser particle size analyser called as a Mastersizer 2000 (Malvern Instruments Ltd., UK) was used to measure the mean particle size of the food powders. The density measurement is a very important means to characterise the compaction process, particularly for a material in the form of a powder. The densities can be divided into bulk density, tapped density, true density, and apparent density [2]. Based upon the bulk density and the tapped density measurements, the Carr Index [11] and the Hausner Ratio [12] were calculated to determine the degree of powder flow. The moisture content was measured using a conventional oven method, whereby the sample was dried until a constant weight was achieved. The powder morphology was obtained from a Scanning Electron Microscope (SEM) (JSM-5300 Scanning Microscope, UK) and Figure 2 shows the SEM images of the food powders used.

Table 1: Food powder properties

Powder Properties	Fine Maize	Coarse Maize	Avicel
Mean particle size $d_p \times 10^{-6}$/m	135.0 ±15.0	632.5 ±23.5	80.0 ±20.0
Bulk density $\rho_b \times 10^3$ /kgm^{-3}	446.25 ±23.50	689.20 ±32.12	361.51 ±17.66
Tapped density $\rho_t \times 10^3$ /kgm^{-3}	697.60 ±18.25	759.80 ±21.44	462.98 ±12.31
True density $\rho_s \times 10^3$ /kgm^{-3}	1504.70 ±16.00	1476.10 ±25.23	1603.60 ±11.21
Apparent density $\rho_g \times 10^3$ /kgm^{-3}	850.00 ±16.43	1356.16 ±19.85	1213.53 ±9.47
Bulk porosity ε_b (%)	47.50 ±0.05	49.18 ±0.07	70.21 ±0.03
Carr Index *CI* (%) [11]	39 (poor flowability)	9 (free-flowing)	22 (free-flowing)
Hausner Ratio *HR* [12]	1.6 (poor flowability)	1.1 (free-flowing)	0.8 (free-flowing)
Moisture content *Mc* (%)	11.11 ±1.03	9.05 ±0.95	4.50 ±0.99

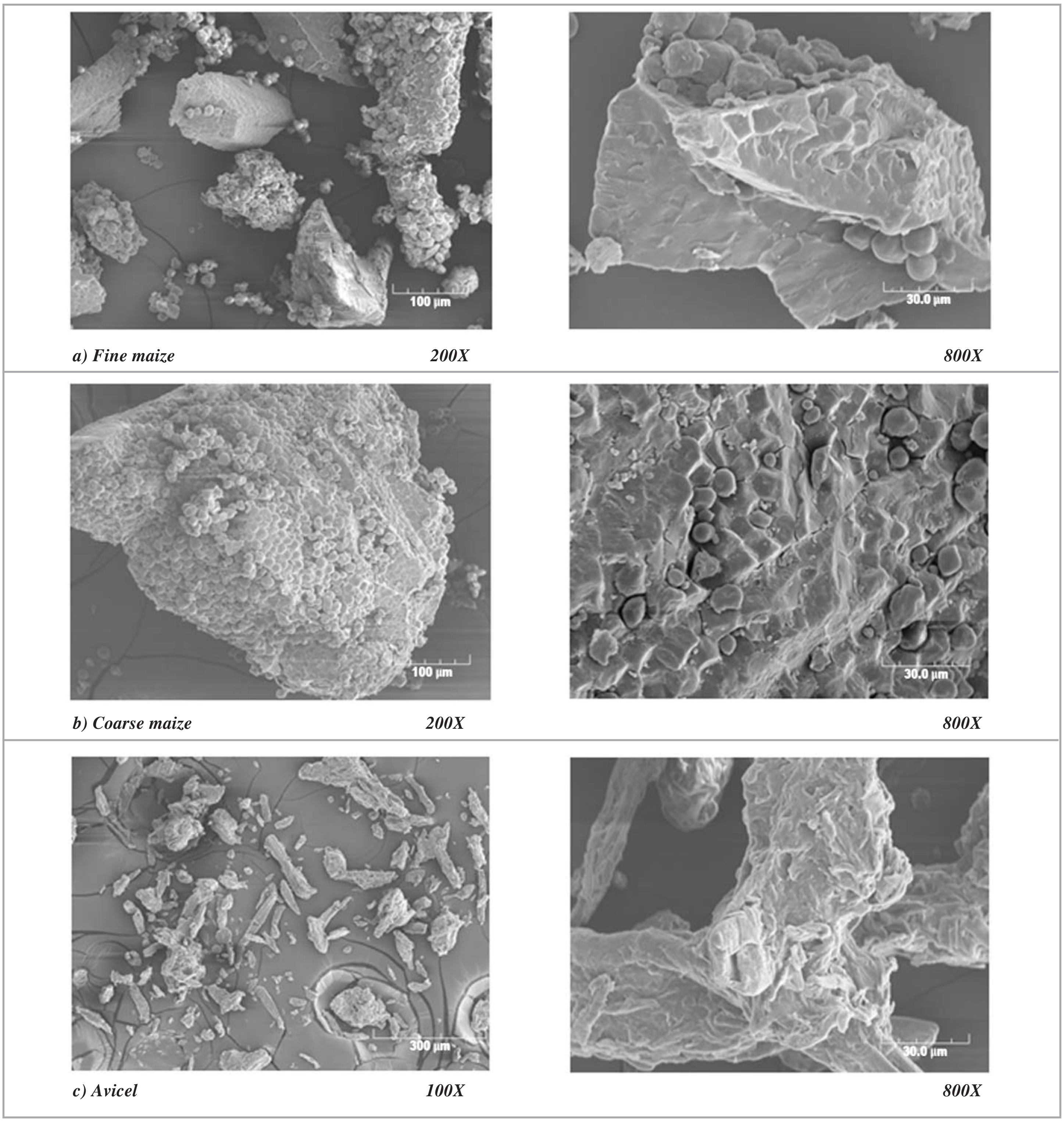

Figure 2: SEM images of (a) fine maize, (b) coarse maize, and (c) Avicel

2.2 Uniaxial Die Compaction

A commercial die compaction machine, EZ-50 Materials Testing Machine (Lloyds Instruments Ltd., UK) was used for compression (Figure 3). The crosshead was equipped with a high precision servo motor and Direct Current servo system where the minimum crosshead velocity was 0.01 mm/min and the maximum crosshead velocity was 100 mm/min. The machine frame was used to prevent any side loading of the material under test and a microprocessor system was used to control the machine, allowing a multi-position control console. An applied force transducer (Sensotec Inc., USA), with a maximum allowable force of 5.0×10^4 N (50 ± 1 kN), and a displacement transducer were installed and connected to the amplifier, converter card, and finally to the computer. This machine could perform loading and unloading, stress relaxation, creep, fracture and other material testing by using NEXYGEN software. In order to compress the powder, a cylindrical stainless steel die (Specac, UK) of diameter 20 ± 0.5 mm with flat-faced punches was used where the internal roughness of the component was at a roughness of approximately 0.3 µm centre average.

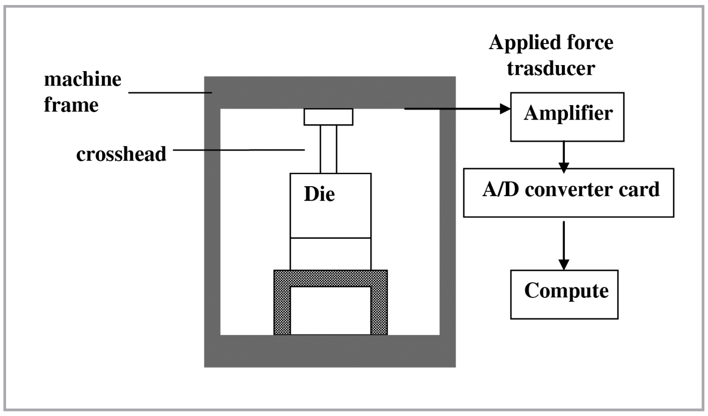

Figure 3: Schematic layout of the uniaxial die compaction system

2.2.1 Machine Compliance

The machine compliance depends upon the type and dimension of the die used. The compliance test for the 20 mm cylindrical stainless steel die was carried out by compressing the die to an ultimate force of 49.5 kN at a crosshead speed of 0.05 mm/min with the 50 kN load cell. A plot of the applied force against displacement was obtained by linearly fitting the loading curve, and the compliance relationship was:

$$h_{comp} = 0.0359P + 0.6327 \qquad (2)$$

where h_{comp} was the displacement of the die during the compliance test (mm) and P was the applied force (kN). For the rest of the experiments, the displacement h generated from the die was subtracted by the displacement obtained from the compliance test, h_{comp}.

2.2.2 Experimental Procedures for Uniaxial Die Compaction

Firstly, 0.003 kg (3.00 ± 0.01 g) of the powder was poured gradually using a plastic funnel into the cylindrical stainless steel die. A 1.0×10^4 N (10 ± 1 kN) force was applied from the upper punch with a crosshead speed of 0.5 mm/s. This process was called the 'loading' process. After the desired force was reached the 'unloading' process occurred where the applied force was automatically removed from the upper punch. The data of the applied force corresponding to the displacement was logged into the personal computer. In order to eject the compact from the die, the bottom punch was removed and the upper punch was consolidated. The thickness of the compact was measured using a 25 mm External Micrometer (Vernier, England). It should be noted that the moisture content of the powder was measured prior to the compaction process, and was then kept in an airtight plastic bag and stored in a sealed jar containing silica gel before further characterisations.

Compression tests were repeated for the applied forces of 20 kN, 30 kN, 40 kN, 45 kN and 49 kN. These procedures were carried out for fine maize, coarse maize, and Avicel without the addition of binder or thermal effects and under ambient conditions, with the ambient temperature range of 22-24°C and the relative humidity between 33 to 43%.

2.3 Tensile Strength Test

A diametrical compression test was adopted to measure the tensile strength of the compacted powder as given in [10]:

$$\sigma_t = \frac{2F}{\pi DH} \qquad (3)$$

where F is the crushing force or tensile force (N), D is the compact diameter (m) and H is the compact thickness (m). The compact was placed between the two flat plates and the force was applied until the compact fractured. The force transducer used for the compression was a 1.00 ± 0.01 kN applied force transducer, and connected to the EZ-50 Materials Testing Machine. However, a 50 kN force transducer was used to test Avicel due to its large tensile strength. The crosshead speed used was 0.70 mm/min, with preload of 2 N and force drop after rupture for data recording was set at 85%.

3.0 RESULTS AND DISCUSSIONS

3.1 Applied pressure-Volume Relationship

At 0.003 kg (3 g) of fine maize, coarse maize, and Avicel powders were each compacted at ambient conditions with the initial aspect ratios (*H/D*) of 0.75, 0.70, and 1.18 respectively. In order to avoid any possible effect of the compression speed, the crosshead speed of the upper punch was applied at 0.05 mm/min for all of the powder compressions. Figure 4 shows that as the applied pressure increased, the volume of the compact decreased for all the powders used. When the powders were compressed at approximately 30 MPa, the volume of the compacts were 3.11×10^{-6} m^3 for fine maize powder, 3.00×10^{-6} m^3 for Avicel powder, and 2.84×10^{-6} m^3 for coarse maize powder. 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 the Carr Index (Table 1). These indices may be used to qualitatively provide the extent of the inter-particle friction upon flowability, using categories such as free flowing, medium flow, and difficult to flow. Coarse maize powder had the lowest volume because of its free-flowing characteristic that allowed the effect of the gravitational force to be larger than the inter-particle force. Therefore, when the coarse maize was poured into the die, a close particle packing structure was formed; hence, less energy was required to overcome the inter-particle friction, and induced the greatest inter-particle contact area. However, for Avicel powder, even though it had a free-flowing characteristic, its small mean particle size accommodated greater inter-particle friction, consequently requiring a larger amount of energy to overcome the inter-particle friction. Fine maize powder, which was cohesive 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. The compaction process may be divided into three stages - Stage I, II, and III. Stage I is considered to occur at the applied pressure of 70 MPa and below. All of the particles rearranged and slid at this stage. At 70 MPa, the Avicel and coarse maize volume coincided with each other. However at higher applied pressure, the Avicel powder started to reduce in volume greater than the coarse maize powder. This change made the lowest compact volume at Stage II of the compaction process to be that of the Avicel powder, followed by the coarse maize and fine maize powders for the applied pressure range of 70 to 120 MPa. However, the volume variation between fine maize, coarse maize, and Avicel powders were relatively small. This stage can be considered as an intermediate process where the particles undergo sliding and rearrangement to fill in the void spaces.

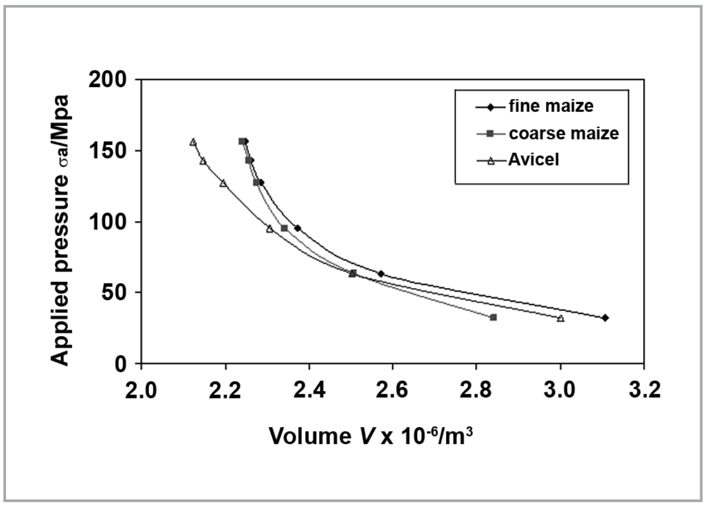

Figure 4: Applied pressure-volume relationship of powders at ambient conditions. The lines are the trend lines

Another point worthy of mention is the deviation of the compacts' volume between fine maize and coarse maize at an applied pressure lower than 140 MPa. It was found that coarse maize had a lower compact volume compared to fine maize compacts which indicated that the compactability of the coarse maize was better compared to fine maize. This phenomenon can be postulated to the effect of fragmentation that may had occurred within the compacts of the coarse maize and which can be attributed to its slightly-more-brittle characteristic as its particles are larger than that of the fine maize powder. This postulation can be observed from the visual inspection where the compacted coarse maize would be easily broken when subjected to impact or loading. Fragmentation may have caused the fracture particles to fill in the void spaces, and hence reduced the compacts' volume. This supports the findings of Mattsson and Nyström [13] for compaction of calcium carbonate, the brittleness of which, allowed fragmentation to occur.

Finally, at Stage III, which was between the applied pressure of 120 MPa and above, the difference of the Avicel compact's volume was significantly lower than the fine maize and coarse maize powders, particularly at the applied pressure of 160 MPa. The ductile behaviour of the Avicel powder allowed the compact's volume to decrease significantly, enhanced the inter-particle and intra-particle bonding, and induced plastic deformation. Furthermore, the flake shape and rough surfaces of Avicel powder had induced junctions of contacts from the asperities (Figure 2c), and this could lead to energy dissipation at the contact points [14]. However, fine maize and coarse maize, which were quite spherical and had smooth surfaces (Figures 2 a and b) had less junctions of contacts, perhaps due to the existence of less asperities. This fact is in line with Wong and Pilpel's [15] findings that irregular shape and high surface roughness of powders will induce plastic deformation from the high degree of surface asperities.

Note that at Stage III, the volumes of coarse maize and fine maize were quite similar, which was due to the similar chemical composition. Another possible reason the coarse maize was approaching the volume of fine maize compact is that, after a certain extent of fragmentation process, the number of contact points increased, which may have prevented further volume reduction. This argument agrees with Mattson [16] and Mohammed *et al.* [17] for compaction of brittle pharmaceutical powder.

3.1.1 Kawakita and Lüdde [7] Equation

Figure 5 shows an example of fitting the ratio of the applied pressure to the volume reduction as a function of applied pressure for fine maize powder. The values of the constant characteristics, *a* and *b*, derived from the Kawakita equation, are approximately 0.60 and 0.05, respectively (with the regression R^2 value of 0.9988). These values are dependent upon the material properties of the powders. For instance, the constant characteristic, *a* for starch, lactose, and paracetamol are 0.52, 0.51, and 0.48, respectively [18], and the constant characteristic *b* for starch, lactose, and paracetamol are 0.34, 0.62, and 1.11, respectively [18].

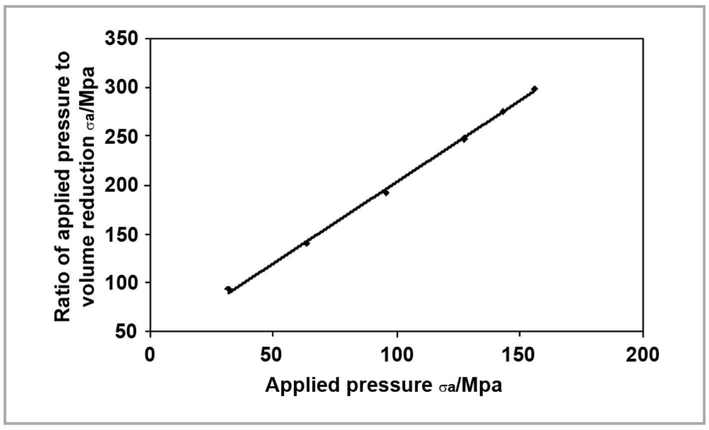

Figure 5: Experimental data fitting into Kawakita and Lüdde (1970/71) equation for fine maize powder at ambient conditions

3.2 Compressibility Factor

Figure 6 illustrates the log-log inter-relationship between the bulk density and applied pressure for fine maize, coarse maize, and Avicel powders. The log bulk density increases as the log of the applied pressure increases. This figure also shows that Avicel has the best compressibility and compactability characteristics compared to fine maize and coarse maize by having very large bulk density. From this inter-relationship the compressibility factor *K* was calculated from the inverse of the slope in the high-applied pressure region of Stage III of the compaction process [8]. The values of the compressibility factor *K* for the food powders are given in Table 2. The *K* value greatly depends upon the material properties. For instance, the *K* value for coffee creamer is 12.50, powdered sucrose is 33.3, and powdered salt is 50.0 [4]. Due care should be paid to these data as only three data points have been recorded in the high applied pressure range.

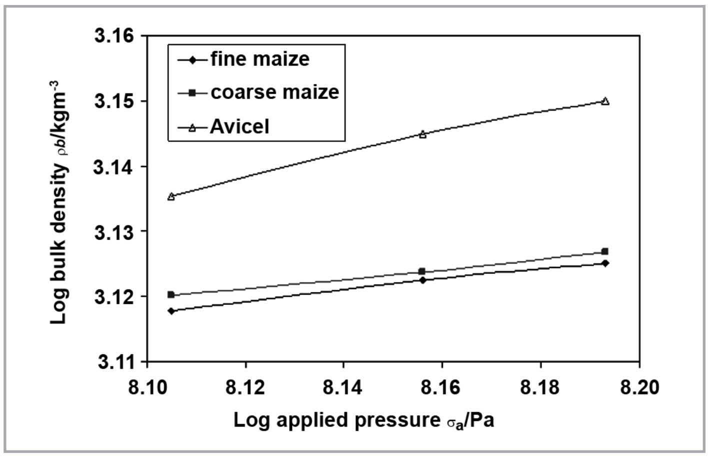

Figure 6: Log bulk density as a function of log applied pressure. The lines are the trend lines

Table 2: Compressibility factor

Food powders	Compressibility factor K	Regression R^2
Fine maize	9.03 ± 1.81	0.9880
Coarse maize	11.14 ± 1.25	0.9983
Avicel	5.43 ± 0.95	0.9941

3.3 Stress Relaxation

The analysis of the stress relaxation curve may allow a simple comparison between the shape characteristics of the curves with different viscoelastic deformable powders. Table 3 shows ranges of the stress relaxation parameters k_1 and k_2 for fine maize, coarse maize, and Avicel powders compacted between the applied pressure of 32 to 156 MPa at ambient conditions. The constant characteristics k_1 and k_2 were obtained by fitting equation in [4]. The values of k_1 and k_2 of the powders used are within the range of the values of k_1 and k_2 for cheese, which range from 42.6-70.8 and 67.2-75.6 s (0.71-1.18 and 1.12-1.26 min), respectively [19]. The value of k_2 was then used to calculate the value of the asymptotic residual modulus E_a of the powders [4].

Table 3: Stress relaxation parameters

Stress relaxation parameters	Fine maize	Coarse maize	Avicel
k_1/s	27.00-72.00	21.38-43.15	13.85-40.01
k_2/s	91.20-126.00	17.63-168.10	16.53-178.56

Figure 7 shows the asymptotic residual modulus as a function of applied pressure for fine maize, coarse maize, and Avicel powders at ambient conditions. The values of E_a increase as the applied pressure increases for all of the powders used. Coarse maize powder has the highest value of the asymptotic residual modulus, followed by fine maize and Avicel powders. In other words, the asymptotic residual modulus value reduces as the ability of the powder to form plastic junctions increases. The fact was also supported by Peleg *et al*. [4] that the asymptotic residual modulus may be used as an index of solidity as it represents components of stress that do not dissipate subject to flow, or particle rearrangement (structural re-orientation). They found that for hard and non-cohesive powder, the asymptotic residual modulus was higher compared to soft and cohesive powder, for instance between glass beads and baby formula milk. This may also be the reason why the value of E_a of coarse maize was higher than for fine maize, even though they had the same surface composition. Coarse maize, which was characterised as hard and non-cohesive, and free-flowing from the Carr Index and the Hausner Ratio, was able to store more elastic work compared to fine maize that was soft and cohesive, as well as difficult to flow [20]. This agrees well with Dobbs *et al*. [21] for compaction of active dry yeast at a relative humidity range of 23 to 86 %. The asymptotic residual modulus and the recoverable compressive work decrease as the relative humidity increases. At low relative humidity, high recoverable compressive work was obtained, which may be used to indicate the ability of the active dry yeast to store elastic strain, and a high degree of elasticity [21]. Nevertheless, Avicel, which has been characterised as a free-flowing powder had an exclusive characteristic. It had an excellent bonding property that allowed plastic deformation to occur, and hence, resulted in the smallest value of E_a.

For the effect of applied pressure, the value of E_a increased as the applied pressure increased for all of the food powders used. This may be related to the ability of the food powders to store elastic strain as the applied pressure increases. Moreover, the high inter-particle friction between the particles may have prevented further internal rearrangement. Therefore, the particles underwent less structural changes.

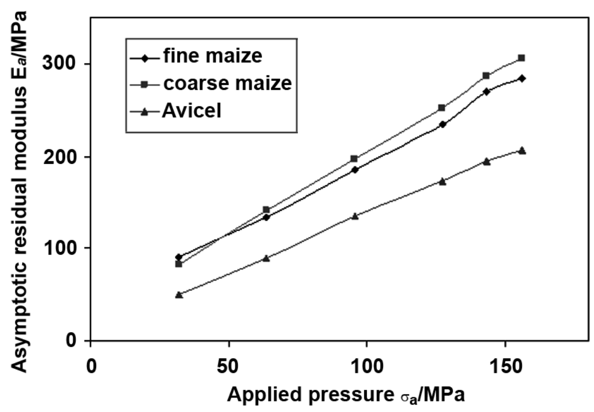

Figure 7: The asymptotic residual modulus as a function of applied pressure. The lines are the trend lines

3.4 Tensile Strength

The compacted maize powders, composed of fine maize and coarse maize at given applied pressures, were tested using a diametrical compression test with a maximum applied force transducer of 1000 ± 5 N (1 kN), whereas the compacted Avicel powder had also been tested using a diametrical compression test, but with the maximum applied force transducer of 50 000 ± 1000 N (50 kN). Different ranges of applied force transducers were used due to the relatively large magnitude between the tensile strength of maize and Avicel powders. The investigations were carried out at ambient conditions. Note that, the compacted maize powder had a dimension of 20 mm diameter and a thickness in the range 6.7 to 7.3 mm, depending upon the applied pressure used to compact the powder.

Figure 8 shows the tensile strength increased as the applied pressure increased for all of the powders used. Table 4 shows the values of slope, intercept, and regression from the linear inter-relationship of the tensile strength and applied pressure. The tensile strength depends greatly upon the material properties. The values of the slopes of the linear inter-relationship of tensile strength and applied pressure for starch, paracetamol, and lactose of 0.0060, 0.0001, and 0.0090, respectively [18].

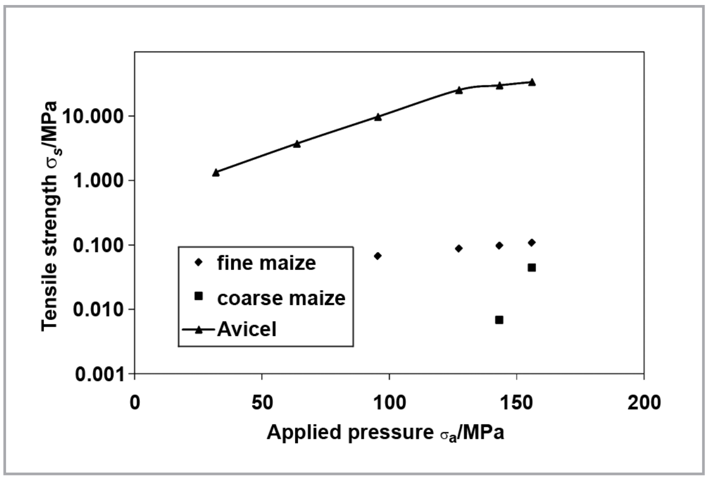

Figure 8: Tensile strength as a function of applied pressure. The line is the trend line

Table 4: The values of slope, intercept, and regression from the linear inter-relationship of tensile strength and applied pressure

Powder	Slope	Intercept	R^2
Avicel	0.2839	-11.835	0.9414

From Figure 8, only 4 compacts were used to evaluate the tensile strength relationship of fine maize powder. For fine maize compacts produced at applied pressure lower than 90 MPa, it was observed that fractures originated from shearing at the loading point. However, at applied pressure greater than 90 MPa, ideal tensile fractures occurred. This can be explained in that, for fine maize, which had a high-dense compact, the powder will form closed-packing by increasing the inter-particle contact area, and thus the inter-particle bonding, which then allows the compact to undergo the ideal tensile fracture. However, in a less dense compact, particularly for compacts produced at low applied pressure, the loose packing of the material was very sensitive to any immediate applied pressure, which resulted in a fractures caused by shear as explained by Newton *et al*., [10]. This is illustrated for the investigation of the tensile strength of coarse maize powder. At higher applied pressure only two compacts had ideal tensile failures, and at lower applied pressure the rest of the compacts failed by shear. As a result, no obvious trend may be observed from the relationship between the tensile strength and the applied pressure of fine maize and coarse maize compacts and thus the data remained unexplained. For Avicel powder, all of the compacts produced had ideal tensile failures, which may be due to ductile characteristics. Thus, this allowed more inter-particle bonding to occur and the formation of plastic junctions, consequently producing tough and coherent compacts.

4.0 CONCLUSIONS

There are three distinct stages of the compaction and compression processes, Stages I, II, and III. At Stage I, particle rearrangement occurred, while at Stage II, particle rearrangement and deformation occurred, both plastic and elastic deformation. At Stage III, particle deformation occurred and the compressibility of the powder started to decrease. When fine maize, coarse maize, and Avicel powders were compacted, Avicel powder showed the highest compactability characteristic, particularly at Stage II of the compaction process, where a pronounced plastic deformation occurred. During the actions of impact and loading, it was observed by visual inspection that, fragmentation occurred to the coarse maize powder, which may be due to the large particle size, which allowed the coarse maize to have a slightly brittle characteristic. This may be the reason why coarse maize powder compacted better at Stage I and II. However, at Stage III, compactability of both the coarse maize and fine maize were quite similar, which may be due to the similar chemical composition. Hence, the strength of the starch junctions were similar. Another reason may be because after a certain stage of the fragmentation process, the number of contact points increased, which may have prevented further volume reduction. Consequently, the compactability of the powder was reduced. Further analysis of the applied pressure-volume relationship was carried out by fitting the Kawakita and Lüdde [7] equation which shows that the validation of data agreed with those from literature. The asymptotic residual modulus value reduced as the ability of the powder to form plastic junctions - assuming that they existed - increased. By using a diametrical compression test, the tensile strength of the compacted powder was determined. Avicel compact showed the greatest tensile strength, many times that of fine maize and coarse maize compacts. However, between the fine maize and coarse maize, fine maize had higher tensile strength which may be due to its smaller particle size, as well as the fact that the contact area may be increased, and consequently may form a more coherent compact. ■

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PROFILES

DR YUS ANIZA YUSOF

Dr Yus Aniza Yusof has been involved in the area of particle technology since her bachelor and MSc in Universiti Kebangsaan Malaysia under supervision of Associate Professor Dr. Siti Masrinda Tasirin. She further enhanced her interest in granulation processes of dry food powders during her PhD study in Imperial College London. She joined Professor Briscoe’s group on compaction and compression of food powders utilising uniaxial die compaction and roll compaction. Upon returning to Malaysia in 2006, she applies her knowledge towards investigating the granulation processes, particularly in tabletting of Malaysian herbs, such as Tongkat Ali, Kacip Fatimah, Hempedu Bumi and Misai Kucing. Currently, she is a senior lecturer and has been recently appointed as the Head of Department of Process and Food Engineering, Universiti Putra Malaysia.

DR ANDREW SMITH

Dr Andrew Smith has a B.Sc in Physics from the University of London and a Ph.D from University of Cambridge entitled "The shear properties of thin polymeric films" supervised by co-author Professor B J Briscoe (1976-1979). He spent 3 years at Cranfield University researching the effects of processing conditions on structure and rheology in injection-moulded short fibre reinforced thermoplastics. From 1982 to 2006 he was at the Institute of Food Research in Norwich latterly as a principal scientific officer and Head of the Biomaterials Science group. During that time he collaborated on the tribology of food powders with Professor Briscoe and his group at Imperial College. He has now taken a part time position at the National Centre for Food Manufacturing of the University of Lincoln.

PROFESSOR BRIAN J. BRISCOE

Professor Brian J. Briscoe studied PhD in University of Hull, M.A in University of Cambridge and DSc in University of London. After receiving his PhD, he held a position as an Assistant Director of Research/Ernst Oppenheimer Fellow (Surface Science), Cavendish Laboratories, Cambridge and later as a Lecturer in Interface Science, Cambridge University. In 1984, he joined Imperial College London as a reader in Interface Science and in 1992 he attained his Professorship as a Professor of Interface Engineering and at the same time held several administrative posts. Currently, he is an Honorary Senior Research Fellow in Imperial College London. His research interests are mainly in the field of solid-solid interactions, particularly where organic polymers form one of the solid bodies. In particular in those factors which are responsible for the friction, adhesion and wear of organic materials.