J. Pharm. Pharmacol. 1984, 36: 421–426
Received February 8, 1984


# The effects of binder film characteristics on granule and tablet properties

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The physical properties of cast films of four polymers, which are used as binders in tableting, have been determined. Films were equilibrated at different relative humidities and tested both in tension, at three rates of strain, and by the use of indentation to determine creep compliance and hardness of the film under load. Granules and compacts have also been made using the four polymers as binders and the properties of these have been measured. One of the polymers, starch, formed a paste that was difficult to mix adequately. With the other three polymers a positive correlation was found between compact crushing strength and the creep compliance, the ultimate tensile strength and the elongation at fracture of the cast films. A negative correlation was found between the compact crushing strength and the Brinell Hardness of the films.

In general the choice of binder for tableting is often made empirically, mainly on the basis of previous use. Recently, Krycer et al (1983) have studied the effect of six binders on the properties of paracetamol tablets and, using other workers' values for binder film characteristics, have suggested that film formation and deformation have significant effects on granule and tablet strengths. In addition they showed that wetting of the substrate had a determining effect on granule and tablet strengths. In each case better film formation and better wetting gave better granules and tablets. Healey et al (1974) reported studies on the mechanical properties of films prepared from a number of tablet binders, but made no attempt to correlate these results with granule or tablet properties.

In this investigation four materials that form films and that are classified into different types by Carswell & Nason (1944), and that are also used as tablet binders, have been studied. The mechanical properties of the films have been measured at various rates of strain, after equilibration at different relative humidities and after drying the films at 20 °C and at 60 °C. Using a fine particle size sand as an inert, but wetted, substrate, we have prepared granules and compacts and measured the mechanical properties of these.

## MATERIALS AND METHODS

The binders used were Gelatin Byco C (Croda Gelatin Ltd, Widnes), maize starch (BDH Chemicals Ltd, Poole), methylcellulose (Methocel A15, Colorcon Ltd, Orpington) and polyvinylpyrrolidone, PVP, mol wt 40 000 (BDH).

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### *Preparation of films*

Films were prepared on glass plates, using a chromatography spreader, from solutions of the binders. The plates were either coated with aluminium foil (starch and PVP) or made hydrophobic using dichlorodimethylsilane. The binder solutions were maize starch 5%, gelatinized at 90 °C; gelatin 25%, prepared at 70 °C; PVP 60%, prepared at 18 °C and methylcellulose 5% prepared at 18 °C. The spread plates were dried either at 20 °C or at 60 °C, the gelatin and PVP films were dried in a constant humidity oven at 81% relative humidity (RH) to prevent overdrying which prevented the films from being peeled from the plates. The detached films were cut into 6 cm × 0·5 cm strips using a template and had thicknesses in the range 50–80 μm. Film thickness was measured at three different points along the film and any showing a variation greater than 5 μm were discarded. The strips were conditioned at the required relative humidity for 7 days at 20 °C, in glass desiccators containing saturated salt solutions to give the required humidity.

### *Tensile test equipment*

A direct Shear Apparatus (ELE, Hemel Hempstead) was modified to test the behaviour of the strips in tension. The Shear cell was removed and replaced with a fixed member consisting of a spring beam held stationary in two vertical supports. Four strain gauges (EA06 125pc 350, Welwyn Strain Measurements Ltd, Welwyn) were fixed to the beam which was held horizontally and perpendicular to the direction of movement of the reversible loading jack of the direct shear apparatus. Specimen grips were attached to the centre of the spring beam and to the end of the loading jack. The strips were aligned using a horizontal platform of adjustable height which was marked with lines parallel to the direction of movement of the jack. Strips were tested to failure in tension and the output from the strain gauges recorded on a flat bed recorder. This produced a load-time profile for each strip, from which a stress/strain curve was determined. From each test measurement values were calculated for Young's Modulus, ultimate tensile strength, toughness, elongation at fracture, elastic resilience and proportional limit (Schmitz 1965).

*Indentation test*

Samples of film were tested using an ICI Pneumatic Microindentation Hardness Apparatus (Ridgway et al 1970; Rowe 1976). Loads were selected to give measurable indentations of less than 6 μm; a two minute test underload was followed by a 4 min measurement with the load removed.

*Preparation of granules*

Granules were prepared in 500 g batches using a Z-blade mixer (Winkworth, Staines) from sand (Grade HPF3, 22 μm, British Industrial Sand, Oakamoor, Staffs.) and solutions of the binders. Gelatin, maize starch gelatinized, and PVP were added as 18·75% w/w solutions; the methylcellulose was added as a dry powder followed by 80 $cm^3$ water. In every case the final binder content of the granules was 3% w/w. The damp masses were screened, through a 2 mm screen, using an oscillating granulator. The granules were dried in a hot air oven at 60 °C to a moisture content of less than 0·5%.

*Preparation of compacts*

Compacts were prepared from the 355–500 μm size fraction using an hydraulic press (Instron Ltd, High Wycombe) at 0·033 $mm\,s^{-1}$. Each compact was made using 550 mg granule (dry weight) in a 12·7 mm circular die with flat faced punches. The die and punch faces were lubricated using a supension, 1%, of magnesium stearate in carbon tetrachloride. Granule and compact strengths were measured using the tensile test equipment modified to operate as an apparatus that would record the force required to crush individual granules (from the 710–1000 μm size fraction) or to cause the compacts to fail in diametral compression. The work done to crush a granule was calculated from the area under the curve from the trace recorded after deducting the work required to deform the bar. Modification of the test equipment was achieved by replacing the grips with flat aluminium blocks running on a horizontal table and by reversing the direction of movement of the loading jack.

Granule friability was assessed using a Roche friabilator with 5 g granule from the 710–1000 μm size fraction, rotated at 30 rev $min^{-1}$ for 5 min; the percentage loss in weight was recorded.

## RESULTS

### *Physical properties of the films*

*Tensile tests*

In order to assess the reproducibility of the method, 60 replicate measurements were carried out using a gelatin film that had been dried at 20 °C and conditioned at 25 °C and 81% RH. Mean values are given in Table 1 together with coefficients of variation and Pearsonian coefficients of skewness (Walpole 1982) for all parameters. The values for 10 separate replicate determinations carried out at a separate time are also given for comparison. The results show a slight skew to the left, negative coefficients, except for elastic resilience, and no significant differences between the values based on 60 or 10 replicates. The term significant difference is used in this paper to mean significant at the $P = 0{\cdot}05$ level. All data was therefore based on 10, or in a few cases 9, replicates and distributions were assumed to be normal for application of statistical tests of comparison.

The results obtained from the four films for three rates of shear and, after conditioning, at four different relative humidities are given in Table 2. One of the materials, PVP, failed to form a coherent film at 65% RH and at 81% RH and so films were conditioned at 58% RH as this was the highest RH at which films could be readily prepared. It can be seen

Table 1. Results of measurements on 60 replicate film strips of gelatin compared with 10 replicates (means with coefficients of variation cv).

| | 60 replicates Mean | cv | Pearsonian coefficient of skewness | 10 replicates Mean | cv |
|---|---|---|---|---|---|
| Young's modulus ($Nm^{-2} \times 10^6$) | 972 | 15·2 | −0·098 | 939 | 17·3 |
| Ultimate tensile strength ($Nm^{-2} \times 10^6$) | 38·9 | 17·0 | −0·138 | 40·1 | 19·0 |
| Proportional limit (%) | 39·7 | 29·0 | −0·139 | 37·3 | 21·2 |
| Elastic resilience ($Jm^{-3} \times 10^5$) | 1·53 | 39·2 | +0·476 | 1·43 | 34·3 |
| Toughness ($Jm^{-3} \times 10^5$) | 18·9 | 23·8 | −0·230 | 18·6 | 37·1 |
| Elongation at fracture (%) | 6·5 | 20·1 | −0·043 | 6·6 | 21·9 |

Table 2. Physical properties of films. Values represent the mean of 10 replicate measurements.

| | | Gelatin Byco C | | | Methocel A15 | | | Maize starch | | | PVP* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Strain rate* | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| | 12% RH | 667 | 680 | 1226 | 658 | 1052 | 811 | 782 | 750 | 1348 | 404 | 457 | 514 |
| Young's | 44% | 924 | 1058 | 1154 | 595 | 1130 | 966 | 1009 | 867 | 1305 | 537 | 414 | 371 |
| modulus | 65% | 771 | 757 | 1140 | 544 | 851 | 801 | 740 | 677 | 1167 | 442 | 363 | 322 |
| ($Nm^{-2} \times 10^6$) | 81% | 939 | 900 | 1247 | 486 | 842 | 797 | 785 | 682 | 1136 | — | — | — |
| | 12% | 34 | 37 | 48 | 68 | 62 | 58 | 34 | 42 | 47 | 14 | 25 | 18 |
| Ultimate tensile | 44% | 32 | 31 | 42 | 59 | 72 | 60 | 33 | 38 | 44 | 15 | 21 | 17 |
| strength | 65% | 27 | 29 | 37 | 54 | 64 | 62 | 36 | 41 | 38 | 14 | 19 | 13 |
| ($Nm^{-2} \times 10^6$) | 81% | 40 | 47 | 57 | 55 | 72 | 58 | 30 | 36 | 31 | — | — | — |
| Proportional | 12% | 56 | 96 | 90 | 63 | 39 | 43 | 68 | 77 | 52 | 58 | 51 | 99 |
| limit (%) | 44% | 45 | 89 | 85 | 74 | 42 | 47 | 70 | 86 | 73 | 77 | 65 | 100 |
| | 65% | 44 | 65 | 93 | 72 | 36 | 38 | 37 | 67 | 55 | 44 | 55 | 94 |
| | 81% | 37 | 48 | 64 | 54 | 24 | 32 | 34 | 54 | 61 | — | — | — |
| Elastic | 12% | 3·4 | 14·4 | 8·1 | 23 | 2·8 | 3·7 | 4·0 | 7·8 | 2·5 | 1·0 | 1·6 | 3·8 |
| resilience | 44% | 1·5 | 5·3 | 5·7 | 18 | 3·3 | 3·9 | 3·5 | 7·4 | 3·9 | 1·5 | 1·7 | 6·4 |
| ($Jm^{-3} \times 10^5$) | 65% | 1·1 | 2·9 | 7·5 | 18 | 3·1 | 3·2 | 2·3 | 6·2 | 2·0 | 0·5 | 1·3 | 3·0 |
| | 81% | 1·4 | 3·5 | 7·3 | 13 | 1·9 | 2·1 | 0·9 | 2·8 | 1·6 | — | — | — |
| Toughness | 12% | 24 | 32 | 23 | 150 | 97 | 103 | 22 | 33 | 34 | 8·4 | 15 | 7·8 |
| ($Jm^{-3} \times 10^5$) | 44% | 15 | 14 | 17 | 134 | 179 | 119 | 24 | 25 | 22 | 6·8 | 8·9 | 13 |
| | 65% | 12 | 15 | 17 | 102 | 121 | 127 | 24 | 35 | 20 | 4·8 | 8·3 | 5·7 |
| | 81% | 19 | 31 | 29 | 114 | 151 | 105 | 18 | 23 | 14 | — | — | — |
| Elongation at | 12% | 8·6 | 8·7 | 4·8 | 27 | 22 | 24 | 8·9 | 8·8 | 8·3 | 7·4 | 7·7 | 4·4 |
| fracture (%) | 44% | 6·5 | 4·5 | 4·4 | 26 | 34 | 25 | 5·8 | 6·7 | 5·9 | 5·0 | 6·2 | 7·1 |
| | 65% | 6·0 | 6·2 | 4·6 | 22 | 27 | 29 | 9·4 | 10 | 6·5 | 4·5 | 5·8 | 4·3 |
| | 81% | 6·6 | 8·8 | 6·2 | 26 | 34 | 28 | 8·9 | 7·9 | 5·3 | — | — | — |

* 1 = 0·0252 mm $s^{-1}$; 2 = 0·0517 mm $s^{-1}$; 3 = 0·074 mm $s^{-1}$.
* For PVP films the values in the 65% RH rows were obtained at 58% RH.

from Table 2 that PVP has significantly lower values for Young's modulus, ultimate tensile strength, and toughness, than the other three materials used. Methylcellulose on the other hand has significantly greater values of ultimate tensile strength, toughness and elongation at fracture. These differences can be summarized in stress/strain diagrams as seen in Fig. 1 for films conditioned at 44% RH and strained at 0·0517 mm $s^{-1}$. Analysis of variance shows that both RH and shear rate have a significant effect in most cases. The exceptions are, for RH: methylcellulose—ultimate tensile strength, toughness and elongation at fracture; maize starch—elongation at fracture. For strain rate: PVP—Young's modulus, elongation at fracture; maize starch—toughness; methylcellulose—toughness and elongation at fracture. With methylcellulose the results for toughness and elongation at fracture are subject to considerable variation and this could mask any dependence of the results on the variables tested. In general, increase in RH leads to a fall in the value of the 6 parameters measured, notable exceptions are a rise in all but proportional limit with gelatin film with a change in RH from 65–81% and considerable variation in results for toughness and elongation at fracture with

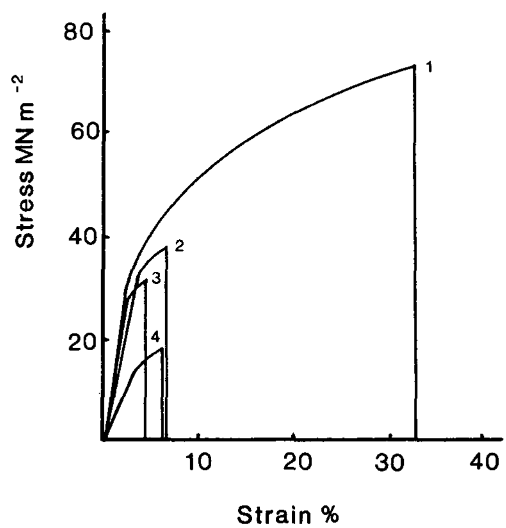


FIG. 1. Stress/strain diagrams for methylcellulose, 1; maize starch, 2; gelatin, 3 and PVP, 4 for films conditioned at 44% relative humidity with a strain rate of 0·0517 mm $s^{-1}$.

methylcellulose. Increase in strain rate resulted in a rise in Young's modulus, except with PVP which showed no significant change. With the other parameters, changes in strain rate resulted in a

Table 3. Comparison of physical properties of films dried at 20 °C with those dried at 60 °C. Strain rate 0·0517 mm $s^{-1}$, conditioned at 44% RH (Gelatin at 65% RH).

| | Gelatin Byco C | | Methocel A15 | | Maize Starch | | PVP | |
|---|---|---|---|---|---|---|---|---|
| | 20 °C | 60 °C | 20 °C | 60 °C | 20 °C | 60 °C | 20 °C | 60 °C |
| Young's modulus ($Nm^{-2} \times 10^6$) | 757 | 1117 | 1130 | 1146* | 867 | 1458 | 414 | 550* |
| Ultimate tensile strength ($Nm^{-2} \times 10^6$) | 29 | 27* | 72 | 70* | 38 | 33 | 21 | 18* |
| Proportional limit (%) | 65 | 79 | 42 | 49 | 86 | 88* | 65 | 59* |
| Elastic resilience ($Jm^{-3} \times 10^5$) | 2·9 | 2·2* | 3·3 | 5·1 | 7·4 | 3·1 | 1·7 | 1·2* |
| Toughness($Jm^{-3} \times 10^5$) | 15 | 8·9 | 179 | 192 | 25 | 10 | 9 | 8* |
| Elongation at fracture (%) | 6·2 | 3·1 | 34 | 37* | 6·7 | 3·2 | 6·2 | 5·3* |

* Difference not significant ($P = 0·05$).

variety of changes which were statistically significant and reproducible but whose origin was not clear. Elongation before fracture tended to fall with increase in strain rate, as might be anticipated from the review by Ritchie (1972). The high values of elastic resilience with methylcellulose at the lowest strain rate result from significant changes in Young's modulus and elastic limit combining to give a much greater area under the curve for the linear portion of the stress/strain diagram.

Drying the films at 60 °C rather than at 20 °C resulted in a number of significant changes in the values of the parameters measured for three of the film materials, but the properties of the PVP films were not affected by drying temperature; the results are given in Table 3. Significant changes that resulted from drying at the higher temperature were increased Young's modulus and proportional limit, decreased toughness for gelatin and maize starch (methylcellulose showed an increase), and decreased elongation at fracture. These changes indicate an increased brittleness brought about by drying at 60 °C even though the films were subsequently conditioned at a fixed temperature and relative humidity.

*Indentation measurements*

The values for Brinell Hardness (Aulton 1977) of the four materials tested equilibrated at two different humidities are given in Table 4. Increased conditioning humidity results in a reduced hardness as would be expected from the plasticizing effect of water in the polymer film. The results for creep compliance, calculated from a selected typical indentation/time profile, as suggested by Barry (1974), are given in Table 5. At 12% RH the initial indentation was completely elastic with no load/time dependent deformation; the methylcellulose film showed much greater elastic deformation.

Table 4. Brinell Hardness values calculated from indentation measurements (MPa).

| RH | Load (g) | Gelatin 20 | Methocel A15 8 | Maize starch 20 | PVP 8 |
|---|---|---|---|---|---|
| 12% | | 18·76 (3·8) | 7·45 (2·5) | 15·67 (3·5) | 9·17 (3·7) |
| 58% | | | | | 3·49 (0·9) |
| 81% | | 9·34 (2·0) | 6·98 (2·0) | 10·50* (2·45) | — |

* 16 g load.

Following removal of the load, a small plastic deformation was seen for all the films. The instantaneous elastic recovery was 90, 78, 64 and 21% for gelatin, methylcellulose, PVP and maize starch respectively. Conditioning the films at 81% RH (58% for PVP) resulted in large changes in the amount of deformation under load with gelatin, maize starch and PVP but no change with methylcellulose; the decrease in Brinell Hardness was also not significant with methylcellulose films conditioned at 81% RH. Conditioning at the higher humidity also resulted in films that deformed both elastically and plastically under load, with an increase in the amount

Table 5. Creep compliance values calculated from a typical profile indentation ($MPa^{-1} \times 10^{-3}$). 1, load applied for 2 min; 2, load removed for 4 min.

| RH | | Gelatin 1 | Gelatin 2 | Methocel 1 | Methocel 2 | Maize starch 1 | Maize starch 2 | PVP 1 | PVP 2 |
|---|---|---|---|---|---|---|---|---|---|
| 12% | $J_O$ | 2·64 | 2·37 | 10·33 | 8·13 | 3·64 | 1·00 | 3·48 | 2·23 |
| | $J_R$ | 0 | 0·08 | 0 | 1·53 | 0 | 2·24 | 0 | 1·08 |
| | $J_N$ | 0 | 0·19 | 0 | 0·67 | 0 | 0·40 | 0 | 0·17 |
| | $J_C$ | 2·64 | | 10·33 | | 3·64 | | 3·48 | |
| 81%* | $J_O$ | 6·40 | 5·25 | 7·00 | 4·13 | 4·2 | 3·23 | 4·00 | 22·62 |
| | $J_R$ | 3·8 | 2·79 | 2·4 | 2·37 | 4·6 | 2·27 | 21·5 | 3·51 |
| | $J_N$ | 0·65 | 2·81 | 0·93 | 3·83 | 0·83 | 4·14 | 1·61 | 0·99 |
| | $J_C$ | 10·85 | | 10·33 | | 9·63 | | 27·11 | |

* PVP at 58% RH.

$J_O$ = Compliance of initial instantaneous deformation, recoverable on removal of load.

$J_R$ = Overall creep compliance of time-dependent elastic deformation, also recoverable with time.

$J_N$ = Creep compliance of plastic deformation, not recoverable.

$J_C = J_O + J_R + J_N$.

of non-recoverable deformation following removal of the load. The PVP film was significantly different in behaviour at the higher humidity level with the major part of the deformation under load being time dependent, but this deformation was recovered instantaneously on removal of the load. These changes are consistent with a softening of the film with increased water content. The result with PVP at 58% RH suggests that the hydrated film deforms slowly under load but that it recovers extremely rapidly once the load is removed. With this material the rate of compression may well have a more significant effect. In tension only Young's modulus and elongation at fracture were independent of strain rate.

*Properties of granules*

Granules were prepared using all four binders and the granules were tested for load to crush, work to crush, mean size and friability. The results are given in Table 6 for granules conditioned at various relative humidities at 25 °C. These results show clearly the formation of very weak, small, friable granules using maize starch as binder and a fall in granule strength at the highest relative humidity used. The only exception was the work required to crush PVP granules equilibrated at 58% RH.

*Properties of compacts*

Compacts were prepared using slow compression, and their diametral crushing strengths obtained. The results are summarized in Fig. 2; standard deviations were less than 10% in all cases. Compact strengths were in the order methyl cellulose > PVP > gelatin > maize starch, the compacts made with maize starch being particularly weak. The increase in strength with pressure was linear in the range 40–200 $MNm^{-2}$ for PVP but with the other three binders the plot of strength against load tends to reduce in slope as the load is increased.

Table 6. The properties of granules prepared using sand and each of four binders.

| Binder | | Gelatin Byco C | Methocel A15 | Maize starch | PVP |
|---|---|---|---|---|---|
| Mean load to crush granule (g) | 12% RH | 242 (128)* | 271 (78) | 140 (85) | 203 (107) |
| | 44% RH | 347 (118) | 324 (82) | 132 (76) | 340 (156) |
| | 58% RH | | | | 294 (136) |
| | 81% RH | 318 (151) | 255 (58) | 96 (59) | |
| Mean work to crush granule ($J \times 10^{-4}$) | 12% RH | 11·2 (7·3) | 15·3 (3·9) | 5·7 (3·2) | 11·2 (4·7) |
| | 44% RH | 14·3 (4·1) | 13·9 (4·0) | 7·8 (4·2) | 10·5 (4·0) |
| | 58% RH | | | | 13·4 (5·5) |
| | 81% RH | 13·9 (7·3) | 13·4 (3·6) | 4·7 (2·9) | |
| Mean granule size (µm) | | 365 | 680 | 200 | 445 |
| Friability (%) | | 14·6 | 5·0 | 20·4 | 11 |

* s.d.

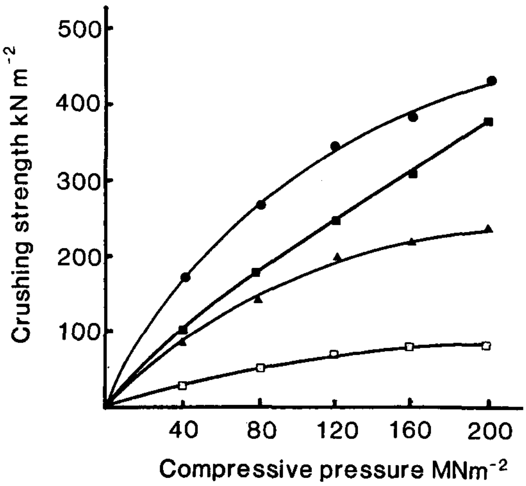


FIG. 2. Diametral crushing strengths of compacts of sand with methylcellulose ●, maize starch □, gelatin ▲ and PVP ■ as binders.

Table 7. Ranking of each property measured for each of the binders used.

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Compacts | | | | | |
| Hardness | | MC | PVP | G | MS |
| Granules | | | | | |
| Size | | MC | PVP | G | MS |
| Least friability | | MC | PVP | G | MS |
| Load to crush 12% RH | | MC | G | PVP | MS |
| Load to crush 44% RH | | G | PVP | MC | MS |
| Work to crush 12% RH | | MC | G = PVP | | MS |
| Work to crush 44% RH | | G | MC | PVP | MS |
| Films | | | | | |
| Compliance: loaded 12% RH | $J_C$ | MC | MS | PVP | G |
| load removed | $J_O$ | MC | MS | PVP | G |
| | $J_R$ | MC | MS | G | PVP |
| | $J_N$ | MS | MC | PVP | G |
| Compliance: loaded 81% RH | $J_C$ | PVP | G | MC | MS |
| | $J_O$ | MC | G | MS | PVP |
| | $J_R$ | PVP | MS | G | MC |
| | $J_N$ | PVP | MC | MS | G |
| load removed | $J_O$ | PVP | G | MC | MS |
| | $J_R$ | PVP | G | MC | MS |
| | $J_N$ | MS | MC | G | PVP |
| Brinell Hardness 12% RH | | G | MS | PVP | MC |
| 81% RH | | MS | G | MC | PVP |
| Young's modulus 20° | | MC | MS | G | PVP |
| 60° | | MS | MC | G | PVP |
| Ultimate tensile strength | 20° | MC | MS | G | PVP |
| | 60° | MC | PVP | MS | G |
| Toughness | 20° | MC | MS | G | PVP |
| | 60° | MC | Ms | G | PVP |
| Elongation at fracture | 20° | MC | MS | G = PVP | |
| | 60° | MC | PVP | MS = G | |
| Elastic resilience | 20° | MS | MC | G | PVP |
| | 60° | MC | MS | G | PVP |
| Proportional limit | 20° | MS | PVP = G | | MC |
| | 60° | MS | G | PVP | MC |

## DISCUSSION

To assist the discussion of the relations between binder film, granule and compact properties the numerical values for each parameter have been ranked for each of the binders in Table 7. The compact hardness and granule size are found to be much less than expected from the film properties with maize starch as binder. These results, for maize starch, suggest strongly that the distribution of the binder to the points of contact is important and that this is inhibited by the high viscosity of the maize starch paste used. If the results obtained using maize starch are ignored and compact hardness and low granule friability are taken as desirable properties, then it can be seen that these properties correlate positively with granule size, film compliance, $J_O$ at 12% RH (loaded) and $J_O$ and $J_N$ (load removed). Ultimate tensile strength and elongation at fracture; a negative correlation is seen with Brinell Hardness (12% RH). It would appear, therefore, that a good binder will be one that is strong (high ultimate tensile strength), soft (low Brinell Hardness) and with a high compliance when dry. This is a material which is strong in tension but readily deformable. In this initial study it is not possible to decide that these correlations are necessarily significant. However, it is clear that the physical properties of the film do not correlate simply with granule and compact properties. In addition, the importance of adequate binder distribution is emphasized.

*Acknowledgements*

The authors wish to thank ICI Pharmaceuticals, Macclesfield for the loan of the ICI indentation apparatus; Colorcon, for supplies of Methocel; British Industrial Sand for the HPF3 sand and Croda Gelatin Ltd for the Gelatin Byco C.

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