DRUG DEVELOPMENT AND INDUSTRIAL PHARMACY, 10(4), 541-561 (1984)

THE MECHANICAL PROPERTIES OF HYDROXYPROPYLMETHYLCELLULOSE FILMS DERIVED FROM AQUEOUS SYSTEMS

PART 2: THE INFLUENCE OF SOLID INCLUSIONS*

M. E. Aulton** and M. H. Abdul-Razzak
School of Pharmacy, Leicester Polytechnic, Leicester, England
and J. E. Hogan, Colorcon Limited,
Murray Road, St. Pauls Cray, Orpington, Kent, England.

ABSTRACT

Solids in the form of colour pigments are commonly added to tablet film coats for the purpose of identification. This work examines the effect of their addition on certain mechanical properties of the films. Films were cast from aqueous solutions of hydroxypropylmethylcellulose (HPMC) in which the solids had been dispersed. Titanium dioxide was added in concentrations of up to 40% in the dried film. Two grades (regular and high tinting) of the following aluminium lakes (Colorcon Limited) were also investigated: Brilliant Blue FCF, Erythrosine and Tartrazine. A tensile test was performed on the films using an Instron test machine. In general, the addition of solid particles reduced the tensile strength of the film, shortened the elongation at break and increased the elastic modulus, i.e. the films became more brittle. The influence of storage humidity on these properties is also reported.

Changes in these fundamental properties are correlated with practical problems associated with the addition of solid particles to films. The way in which the presence of solids affects the desirable mechanical properties of tablet film coats is also discussed.

---

*Part of this work was first presented to the 41st International Congress of Pharmaceutical Sciences of F.I.P., Vienna, September 1981.
**Correspondence

0363-9045/84/1004-0541$3.50/0

INTRODUCTION

In Part 1 of this work[1], we examined the effects that certain plasticisers had on the properties of hydroxypropylmethylcellulose (HPMC) films which had been cast from aqueous solutions. In this work we extend the study to cover the addition of solids to similar films.

The consequences of the addition of titanium dioxide and some aluminium lakes on certain mechanical properties of HPMC films (which in turn, reflect the servicability of the film coat) are reported.

Opacifiers, Extenders and Fillers - Opacifiers are usually inorganic materials that are added to film coating formulae to provide hiding or covering power. Materials such as talc, calcium sulphate and calcium carbonate are used for this purpose but by far the most widely used opacifier is titanium dioxide. This is well suited for pharmaceutical work because of its superior covering power and extreme whiteness. It is also relatively inert and lacking in toxic effects. The anatase modification is the type most frequently used due to its chemical purity.

Extenders and fillers are a miscellaneous group which are occasionally added to film coatings to reduce overall costs or to perform a specific function such as prevention of tackiness or modification of surface appearance.

To some extent the functions of these materials overlap, for instance, talc reduces the stickiness of some formulations, improves lustre and it also serves as an opacifier. Whilst titanium dioxide is primarily an opacifier it will serve to reduce polymer tackiness.

Opacifiers and fillers should be water insoluble, have a low water vapour absorption and have a good stable colour. Fillers and extenders should achieve the desired characteristics at lowest cost.

Colours - Colours are added to pharmaceutical tablet film coats to provide elegancy and aid product identification. Colourants also usefully conceal or modify any undesirable appearance which may be inherent to a particular preparation (e.g. to conceal batch-wise variation in the appearance of a raw material).

The most practically useful film colourants may be classified into the inorganics (such as titanium dioxide and the iron oxides) and the organic colours (such as Indigo Carmine and Erythrosine). Another classification is to divide pharmaceutical colourants into soluble dyes or insoluble pigments. The insoluble pigments include the inorganic colours plus the aluminium lake forms of the organic colours. Aluminium lakes of soluble organic dyes are formed by adsorbing the dye on hydrated alumina of very small particle size. The structure of these aluminium lakes is complex and the fundamental particle is very small. These insoluble pigments, including the aluminium lakes, show distinct advantages over the use of water soluble dye for colouring tablet films. Hess and Schrank[2] consider that they have all but replaced the water soluble dyes for colouring film coatings. Their insoluble nature means the particles are physically held within the polymer matrix and are unable to migrate as do the soluble colours which are prone therefore to mottling and poor colouring power. Batch to batch consistency of tablet colour is easier to control with pigment colours as their colour is due to a surface reflectance phenomenon and is not dependent upon depth of dye coloured polymer coat.

Water soluble dyes, in addition to being functionally inferior to insoluble lakes, also possess other distinct disadvantages. Prillig[3,4] has demonstrated an interaction between Erythrosine dye and HPMC which made water soluble HPMC resistant to gastric juice but readily soluble at a pH above 7. A similar interaction between Brilliant Blue FCF dye and HPMC has been reported by Hawes[5].

Opacifiers, fillers, extenders and pigments all possess the advantage of providing coating solids for a film coat formula with little increase in coating solution viscosity. This is particularly important with aqueous processing as the consequently decreased water content of the coating solution permits faster processing times.

The first paper in this series[1] demonstrated the significant effects on the mechanical properties of aqueous HPMC films arising from the addition of plasticisers. It was thought, therefore, worthwhile to investigate the effect of these other common inclusions in a film coat formula. A limited amount of work has been published on the influence of the addition on solids in pharmaceutical tablet film coats (e.g.[5,6,7,8,9] - see later discussion). Other non-pharmaceutical examples include the affect of fillers on the mechanical properties of polyvinyl chloride[10], polyethylene[11] and polyfluoethylene[12]. Each of these latter examples show the trend of decreasing tensile strength and elongation but increasing modulus and hardness as more solids are included. Although these examples are from the work of polymer science, it was felt that such trends may equally well be true of pharmaceutical systems.

MATERIALS

In this work solid dispersions were prepared in aqueous solutions of the commonly-used film former hydroxypropylmethylcellulose (HPMC) (Methocel E5 Premium, Dow Chemical). Titanium dioxide (BDH, Poole, England) and six aluminium lakes (Colorcon Ltd.) were included as examples of solids which are frequently added to tablet film coat formulations as opacifiers and colouring materials respectively. Two grades, Regular (Reg) and High Tinting (HT), of each of three different colours were investigated (Table 1). The carrier material of the HT lake is of a much finer particle size and more uniform distribution than the Reg grade[13].

TABLE 1

Details of Coloured Lakes Used in this Investigation

Name of Lake	F.D. & C. No.	Type	Nominal Dye Strength
Brilliant Blue FCF	Blue No. 1	Reg	11 - 13%
		HT	11 - 13%
Erythrosine	Red No. 3	Reg	15 - 18%
		HT	15 - 18%
Tartrazine	Yellow No. 5	Reg	15 - 17%
		HT	15 - 17%

METHODS

Preparation of Films

This method basically follows that outlined in Part 1 of this work[1], but will be described here in some detail since a number of modifications to the technique were necessary to minimise potential errors resulting from the introduction of solids into the film. Extra care was needed in bubble removal to reduce the number of defects in the cast film. Centrifugation is, of course, not possible with these suspensions.

Method of Dispersion

A 15% w/v polymer solution was prepared by the following method. Approximately one-third of the calculated amount of water was heated. When hot the solution was stirred using a fan mixer and at the same time the required amount of polymer powder was slowly added to the moving vortex. When all the powder was dispersed the remaining cold water was added. The resulting dispersion was stored for several hours to allow complete solvation of the polymer. The titanium dioxide or coloured lake was then added to this solution by tipping the required weight of powder onto the polymer solution and dispersing it throughout the solution with vigorous agitation (Silverson mixer) for a constant time for each sample to ensure the same degree of dispersion.

Removal of Bubbles

Once prepared the solutions contained many air bubbles which prevented immediate casting and necessitated some method of bubble removal. Air bubbles in the dried film introduce weak spots and stress loci during subsequent tensile testing. Application of a vacuum was only moderately successful and it was necessary to store the solution (in a closed container to prevent evaporation) for 48 hours before casting. To prevent sedimentation of the solids and to maintain a uniform dispersion during this period, it was necessary to stir continuously. A rotating magnetic bar was found to be most successful; other more vigorous means of agitation resulted in the ingress of additional air bubbles.

Casting of Films

The suspension was cast using a thin-layer chromatography applicator. This was filled by pipetting from the bulk of the prepared suspension to avoid any bubbles still remaining at the surface. The suspension was cast on to a flat, dry glass plate which had previously been cleaned with absolute alcohol. The applicator clearance was selected to give a film thickness of about 70µm after drying. The glass plate and its polymer/solids dispersion were then dried overnight on a levelled surface at room conditions and then placed in hot air oven at 30°C for about three hours. The initial air drying improved the quality of the film which in earlier tests had occasionally contained irregularities following forced evaporation.

Cutting of Films

The dried polymeric films were cut from the dried sheet using a scalpel and a stainless steel template. During this and all subsequent handling operations the operator wore polythene gloves to avoid contact of moist and greasy skin (both potential plasticisers) with the dry films. The thickness of each sample was measured with a micrometer at four places over the central parallel section of the test piece (actually measuring 20mm x 6mm), avoiding the edges which can give falsely high readings due to irregularities introduced during cutting. For each system about 12 samples were cut and from these the best five with respect to overall thickness and uniformity of thickness (all ± 5% of mean) were selected for tensile testing.

Storage

Samples were placed in a desiccator at 20^{o}C, either over self-indicating silica gel (RH 10% ± 5%) or over a saturated solution of ammonium sulphate (RH 81%) and stored for seven days prior to tensile testing.

Tensile Testing

An Instron 1026 tester was used at a strain rate of 5 mm/min and an initial grip separation of 40 mm. From the resulting stress-strain curves it is possible to calculate the tensile strength of the film (i.e. the maximum applied stress at the point of breaking), the tensile modulus of elasticity from the initial linear portion of the curve and the percentage elongation (or strain) at break (see Aulton[14] for details).

RESULTS

Before looking at the results, let us consider the desirable properties of a film coat with respect to its mechanical properties, i.e. its ability to remain intact during handling and transport. The measurable factors which can be used to define this have been

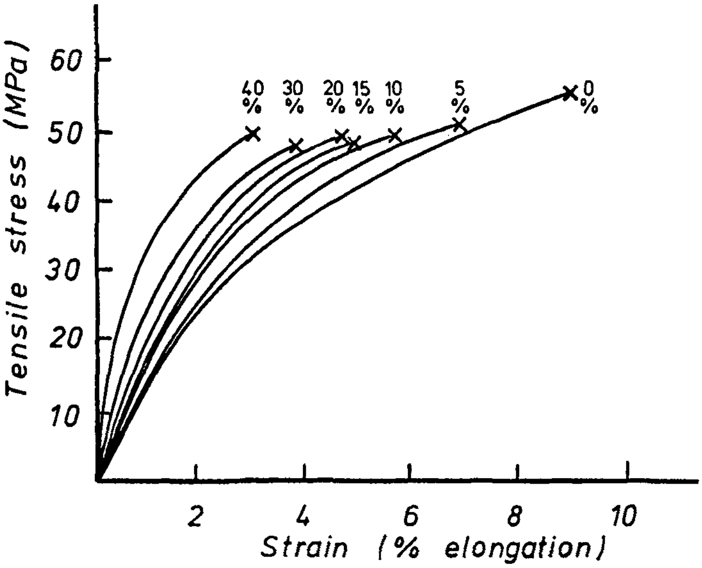

FIGURE 1

Stress-strain curves for cast HPMC films loaded with titanium dioxide. The films were stored at 10% RH prior to testing. The figures on the curves refer to the TiO_2 concentration ($\%^w/w$) in the dried films.

discussed previously[1,14]. To summarise here, a film coat should be hard and tough without being brittle. These properties are reflected in a high value of tensile strength, a high modulus of elasticity and substantial percentage elongation at break when subjected to a tensile elongation test.

1. Titanium Dioxide

(a) Concentration

The effects of the addition of varying concentrations of titanium dioxide on HPMC stress-strain curves are shown in Figure 1. These data are for films stored at low humidities to reduce any possible effects caused by the presence of water, which was shown[1]

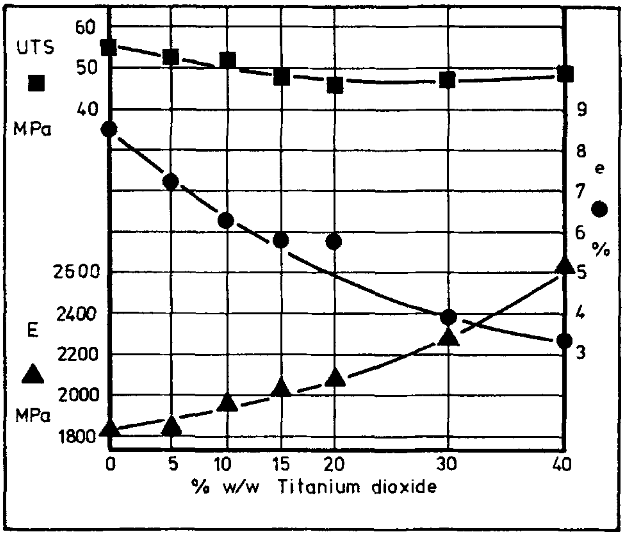

FIGURE 2

Graphical representation of the effect of titanium dioxide addition on mechanical properties of cast HPMC films.
UTS - ultimate tensile strength (MPa), E - modulus of elasticity (MPa), e = elongation (%).

to have a plasticising effect on HPMC. Changes in mechanical properties of the films that occur as the concentration of titanium dioxide was increased are also shown graphically in Figure 2.

The tensile strength of the films fell by only about 13% throughout the concentrations studied. Over the same concentrations the percentage elongation at break fell from 8.7% to only 3.3% - reduction of over 60%. At the same time, the modulus of elasticity increased by 45%. Similar observations have been reported by Delporte[7,8] for HPMC 5cP films containing concentrations of up to 50% in the final film. Studies by Porter[6] however, suggested a greater percentage reduction in strength as the solids concentration increases. His data were obtained from free films prepared by spraying polymer/solid dispersions onto a vinyl-coated card fitted to the inside of a coating pan.

The advantage of presenting the stress-strain data as in Figure 1 is that it emphasises the significant reduction in the toughness of the film (as reflected in the area beneath the curves) as solid is added to the film. It is, of course, possible to quantify this data and interpret the area under the curve as a measure of the work to rupture the film. Absolute values of work (force applied to film strip x actual length of deformation that must be applied before rupture) are not convenient, because absolute values for one film cannot be directly compared with results from another film of different thickness or geometry of test specimen. Thus, representation of the area under the curve (AUC) in terms of stress x strain is preferred.

The dimensions of AUC are apparently those of pressure (units e.g. Pa) but conceptually it is better to consider this in terms of the work (units e.g. J) that must be applied to break the film. This "Work of Rupture" can be interpreted as follows

$$\text{AUC} = \text{stress} \times \text{strain} = \frac{N}{m^2} \times \frac{m}{m} = \frac{J}{m^3}$$

The work of rupture therefore represents work necessary to rupture unit volume of film. Thus, a value of 5 MJ/m^3 represents an area bounded by 50 MPa tensile stress and 0.1 m/m strain (10% elongation) at break. Calculated values of this property for titanium dioxide containing films are listed in Table 2.

(b) Storage Humidity

TABLE 2

Work of Rupture of HPMC 5cP Films as a Function of Titanium Dioxide Concentration and Storage Humidity

Titanium Dioxide Concentration	Work of Rupture (MJm^{-3}) 10% RH	80% RH
0	3.22	3.20
5	2.26	2.26
10	1.83	1.90
15	1.63	1.61
20	1.53	1.52
30	1.24	1.28
40	1.08	1.00

A direct comparison between the mechanical properties of HPMC films stored at 10% and 80% can be seen in Figure 3. Generally, with increasing humidity of the ambient air there is a decrease in tensile strength, a decrease in elastic modulus and an increase in the elongation at break.

The films therefore have approximately the same toughness. This was confirmed by calculation of the area under curves in terms of MJ/m^3. These are listed in Table 2 and clearly show the similar overall toughness of the film.

2. Aluminium Lakes

(a) Concentration

The addition of these insoluble lakes had a similar effect on the mechanical properties of HPMC films to those caused by the

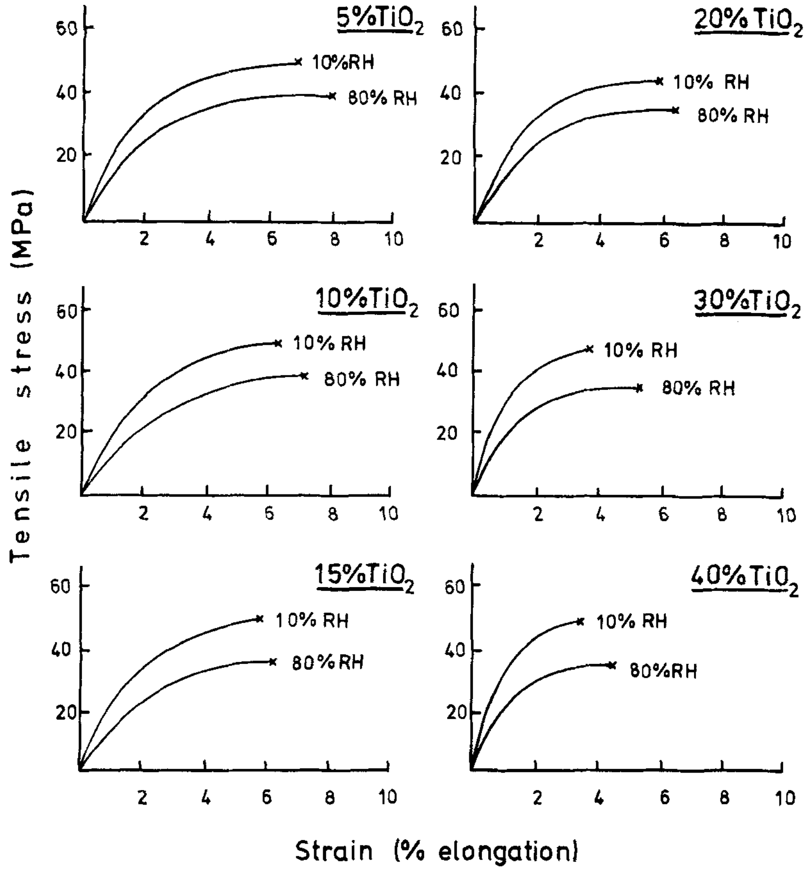

FIGURE 3

Comparative stress-strain curves for cast HPMC films containing 5-40%($^w/w$) titanium dioxide stored at 10% and 80% RH prior to testing.

inclusion of titanium dioxide. The results for Brilliant Blue (Reg) lake are shown as an example in Figure 4. Again, there is a decrease in ultimate tensile strength, an increase in modulus of elasticity and a substantial reduction in elongation (see also Figure 5). There is therefore a corresponding decrease in toughness as shown by the data in Table 3.

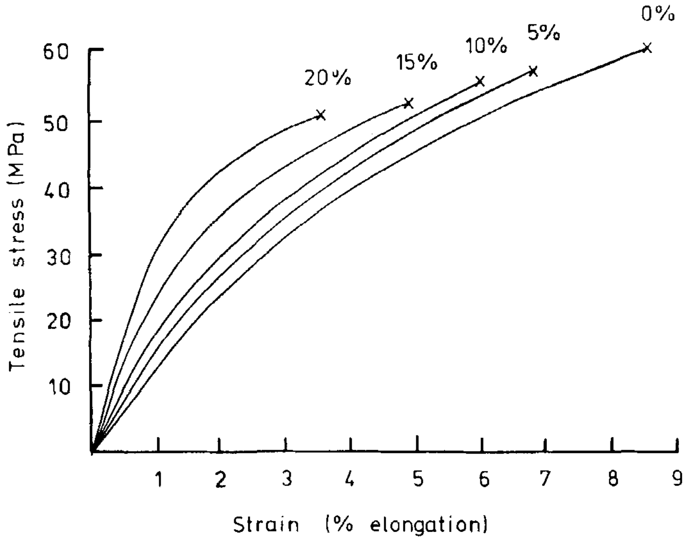

FIGURE 4

Stress-strain curves for cast HPMC films loaded with a regular grade of Brilliant Blue FCF lake (Colorcon). The films were stored at 10% RH prior to testing. The figures on the curves refer to the concentration of lake (%w/w) in the dried film.

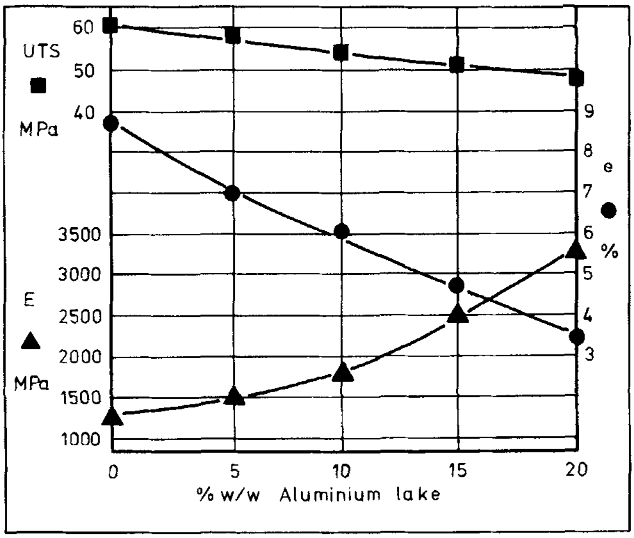

FIGURE 5

Graphical representation of the effect of the addition of Brilliant Blue FCF lake (regular grade, Colorcon) on the mechanical properties of cast HPMC films.

TABLE 3

Work of Rupture of HPMC 5cP Films as a Function of Concentration and Grade of Aluminium Lake

Brilliant Blue Lake	Work of Rupture (MJ m^{-3})	
	Grade	
Concentration	Regular	High Tinting
0	3.22	3.22
5	2.50	2.64
10	2.14	2.37
15	1.75	1.84
20	1.26	1.39

(b) Different Lakes

All the other lakes tested yielded very similar results to those of Brilliant Blue reported above presumably because the particle size and size distribution of the base material was the same in each case. Figure 6 shows the similarity of the stress-strain curves for all three Reg lakes.

(c) Grade of Lake

There were only small differences between the results obtained for the Regular and High Tinting grades of all the lakes tested; their stress-strain curves were similar to those already presented in Figures 4 and 6. However, differences in the overall toughness of the films were detected and these are shown in terms of Work of Rupture as shown in Table 3; the data for Brilliant Blue lake is presented as an example.

In each case the film containing the HT grade was slightly tougher than that containing the Regular grade.

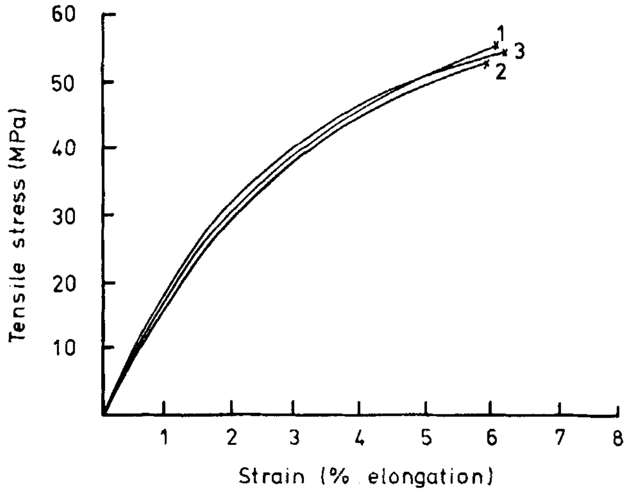

FIGURE 6

Stress-strain curves for cast HPMC films each containing different aluminium lake. All films contained 10%^{w}/w (dried weight) of the regular grade of the following lakes. 1. Brilliant Blue FCF lake, 2. Erythrosine Lake, 3. Tantrazine Lake.

DISCUSSION

The manner in which the presence of solids affects the desirable properties of tablet film coats is worthy of discussion. The description of an ideal film in terms of tensile properties has been mentioned above. The addition of solids affects all of these properties. There is, however, only a relatively small decrease in their tensile strength. This fact, if taken alone, could lead to the misapprehension that the presence of solids was having very little effect on film properties. However, it has been clearly shown here that there are very significant changes in the shape of the stress-strain curves resulting in an increase in brittleness and a decrease in toughness of the film. Therefore, it must be emphasised that changes in all the relevant film properties must be considered in conjunction when assessing the probable overall performance of a film.

With the addition of solids there is a change away from the hard, strong properties[14] of HPMC to a more brittle entity - one which may be less satisfactory in service. In these instances the addition of plasticisers could be beneficial since it has been shown[1,15] for HPMC that their presence increases the maximum elongation before break. Such composite formulations have been studied by Delporte[8] who added propylene glycol and polyethylene glycol 400 in concentrations of 10% and 20% to HPMC 5cP films containing 0%, 12½%, 25%, 37½% and 50% titanium dioxide. Whilst both these plasticisers did improve film ductility, they simultaneously reduced the tensile strength of the films which therefore became weaker. Should an increase in tensile strength of a film be required to overcome for example edge cracking, this can be achieved by the incorporation of higher molecular weight HPMC into the film coat formulation[16]. The ideal additive would be one which increases all the properties (tensile strength, modulus of elasticity and % elongation at break) i.e. one which would greatly increase the toughness of the film.

Many of our results indicate that small changes in the nature of the solid produced little significant effect in the results obtained, as witnessed by the similarity of all six of the aluminium lakes tested. This may suggest that it is simply the presence of solid in a film that is producing the observed effects,

TABLE 4

Brilliant Blue Lake (Regular Grade) in HPMC Films (aq)

Concentration of Coloured Lake in Dry Film (% w/w)	Tensile Strength Observed (MPa)	Tensile Strength Compensated (MPa)
0	60.9	60.9
5	57.4	60.4
10	54.8	60.9
15	51.2	60.2
20	49.3	61.6

i.e. it is not important what the solid is, but merely its concentration. If this were correct we could assume that a film containing 10% solid was weaker because it is only 90% polymer! To test this hypothesis we 'corrected' the measured tensile strength data for the Regular grade of Brilliant Blue (Reg) lake by assuming that the solid contributes no strength to the film (see Table 4). The corrected tensile strength of a film containing 10% solid was therefore calculated as the observed value x 100/90. The results in column 3 of Table 4 are in very close agreement supporting the hypothesis. However, if this form of calculation is repeated for the other tensile properties there are still significant difference even in the 'corrected' values, i.e. there is still an additional reduction in elongation at break of about 50% and a further 2-fold increase in modulus.

It appears, therefore, that observed changes in mechanical properties are not merely due to a reduction in HPMC content but that solids do have some other effect on film properties. This has also been suggested by Rowe[9]. He has shown[17] how the type of particle (presumably size, size distribution and particle shape are important) does indeed have an influence on the mechanical servicability of the film specifically with respect to edge splitting of coated tablets. He has shown the great potential of using changes in the quotient of the tensile strength and elastic modulus of a film to predict such behaviour.

Our results have shown that at high solids loadings the character of HPMC changes from a hard, strong material to one which is rather more brittle. However, formulation measures have been indicated which can aid in overcoming these disadvantages should they prove a problem in practice. In film coating the use of opacifiers, pigments and fillers represents a degree of compromise.

Whilst accepting the foregoing disadvantages, in the situation as a whole, it is recognised that the proper management of solid additions to film coatings permits easier and quicker processing and provides, in the case of pigments, a ready aid to identification. Furthermore, studies have shown that solids, in the form of pigments and opacifiers, assist in the reduction of water vapour transmission across the film[6].

CONCLUSIONS

The two papers in this series have indicated the necessity of considering all the mechanical properties of tablet film coating films when formulation additives are necessary or suggested. Film coats must be tough enough to withstand handling in service. The tests outlined here in conjunction with the table of desirable properties mentioned earlier show how the mechanical properties of a film can be quantified to allow adverse properties such as brittleness and edge splitting to be predicted and therefore avoided by better formulation.

In practice, coloured lakes and titanium dioxide have important functions to perform. Thus, even when it is demonstrated that their addition is detrimental to mechanical properties (particularly at high concentrations), these disadvantages are often outweighed by their positive features.

REFERENCES

1. Aulton, M.E., Abdul-Razzak, M.H. and Hogan, J.E., Drug Dev. and Ind. Pharm., 7(6), 649 (1981).
2. Hess, H. and Schrank, J., Acta Pharmaceutica Technologica Supplement 8, 77 (1979).
3. Prillig, E.B., J. Pharm. Sci., 58, 1245 (1969).
4. Prillig, E.B., U.S. Patent 3,639,565.
5. Hawes, M.R., 'The effect of some commonly used excipients on the physical properties of film formers used in the aqueous coating of pharmaceutical tablets', R.P. Scherer Award, 1978.
6. Porter, S.C., Pharm. Tech. 4(3), 67 (1980).
7. Delporte, J.P., 2nd International Conference on Pharmaceutical Technology, APGI, Paris, June 1980, Vol. V p.6.

8. Delporte, J.P., J. Pharm. Belg., 36(1), 27 (1981).

9. Rowe, R.C., Pharm. Acta Helv., 57 (8), 221 (1982).

10. Phillips, I. and Youde, P.G., Brit. Plast., 30, 297 (1957).

11. Frissell, W.J., Plast. Technol., 2, 723 (1956).

12. Crane, J., "Teflon", Form No T-104, Du Pont Technical Literature.

13. Colorcon Limited, Technical Literature.

14. Aulton, M.E., Int. J. Pharm. Tech. & Prod. Mfr., 3(1), 9 (1982).

15. Delporte, J.P., J. Pharm. Belg., 35(6), 417 (1980).

16. Rowe, R.C., J. Pharm. Pharmac., 32, 116 (1980).

17. Rowe, R.C., J. Pharm. Pharmac., 33, 423 (1981).