Roughness Model for Adhesion Testing of Pharmaceutical Coating Materials

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Abstract

Objective
Roughness is the main parameter in interlocking bonding mechanism. Yet there is no model designed to evaluate the effect of surface roughness on adhesion of coating materials in pharmaceutical sciences.
Materials and Methods
In this study polymethyl metacrylate spherical beads with different sizes were poured into 10 mm mold, then it was pressed by hand screw and finally heated to 141° C. The texture of the resulted surfaces of the discs was quantified and qualified for roughness using Surface Texture Measurement Instrum Model Sarcum110 and SEM, respectively. Solutions of Hydroxypropylmethyl cellulose (HPMC E15) and polyvinylpyrrolidon (PVP K90) were used as binding agents. After conditioning, shear testing technique was carried out for bond strength evaluation using calibrated shear cell bar.
Results
The resulted bond strengths were in the rank order of decreasing particle size and HPMC E15 resulted in higher bond strength.
Conclusion
It could be concluded that this model of roughness, which is easy to prepare, is suitable for studying adhesion of pharmaceutical binders.

Keywords: Adhesion, Adhesive, Binder, Coating materials, Polymethl methacrylate (PMMA), Roughness.

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Introduction

Surface roughness is an important parameter in pharmaceutical tablet dosage forms. Surface roughness has been shown to have an influence on or to reflect the changes in many process variables, such as choice of excipients and compression pressure that affect the final quality of the product. The surface roughness of uncoated tablets plays an important role in relation to dissolution, friability, and adhesion of sugar coatings and polymer film coatings (1-6). In other studies (7-8), surface roughness of film-coated tablets has been connected to dissolution rate, permeability, and the gloss.

Surface roughness is one of the most important parameters in engineering the surfaces. Therefore, various theories and models have been developed for surface roughness assessment. Nowadays a standardized device for surface roughness measurement is based on the use of a diamond stylus. Unfortunately, the stylus records a surface profile along a very thin line, and therefore it gives only surface roughness in one dimension (typical stylus tip diameter is 5 μm and the measurement lag length is typically ranging between 1–10 mm). However, it is possible to make stepwise scans by a stylus on a rough surface. In this case an estimate for three-dimensional profile can be obtained. Nevertheless, such a measurement is usually a time consuming.

It is well known that roughening the surface of solids could change many aspects of the surfaces including adhesion and bond formation. In other words, roughening a substrate can exert a positive effect on joint strength by increasing contact area, introducing an irregular surface geometry and increasing the tendency of an adhesive to spread and/or interpenetrate into the substrate surface. This may be intensified when it has random profile.

Due to the importance of estimation of various surface roughness parameters, other types of non-destructive measurement methods have been developed during the last few decades. Especially, optical techniques have been found useful for the real time industrial measurement of surface roughness.

On the other hand, roughness could introduce negative effects on adhesion by introducing voids to the interface (9). These flaw or discontinuities could play as a source of stress or points of weakness within the adhesive/substrate interface.

Many attempts have been concentrated on quantifying surface roughness by means of different techniques and relating them to other parameters; e.g profilometry to study roughness of tablet coatings (10), shape factor based on image analysis to study roughness of tablet coating of pellets (11), laser beam for studying the surface of compacts (12), atomic force microscopy, (AFM) to examine adhesion of bioadhesive polymers to the buccal cells (13,14), Scanning Prob Microscopy (SPM) technique for quantifying the surface roughness of lactose in relation to deposition of a drug (15) and finally optical surface roughness for qualifying roughness of starch acetate compacts (16).

Instrumental roughness measurement of coated and uncoated tablets was conducted (10) applying many roughness parameters which quantified surface roughness. Normally the R_a (arithmetic mean roughness) value defined as the arithmetic average value of the departure of a profile above and below the reference (centre of electrical mean) is used, but it can not be used to fully describe the surface and more parameter are thus required. Accordingly, the British standard (B.S. 1134 ,1972) lists in addition to the R_a value the R_z (ten point height of irregularities) values defined as the average distance between the five highest peaks and the five deepest valleys within the sampling length measured from a line parallel to the

reference but not crossing the profile. Since this parameter can only be determined graphically and hence required an analogue record of the surface profile, a similar parameter, the R_{tm} value, was defined as the average of five peaks to valley distances. This parameter has been used by Nadkarni *et al.* (17) in describing tablet surfaces. Other parameters often used in the analysis of surface finish are the R_t value, defined as the distance between the highest peak and deepest valley, and the R_p value defined as the distance between the highest peak and the centre line. Invariably R_a will be the smallest measurement, R_p will be greater than R_a and R_t will be the largest measurement. R_{tm} because of its definition will always be a fraction of R_t. The ratio of R_{tm} to R_a gives an overall indication of the type of surface profile. Nowadays SEM gives insight of surface but it fails to give values of surface parameters that are the curvature and the departure from the reference line. In all of the studies done it is always needed to measure the individual surface parameter and relate them to phenomenon in questions. It is appreciated that no work, at least in pharmaceutical fields, has been conducted to introduce a model roughness to provide a hard, symmetrical and reproducible rough surface texture for keeping this parameter constant in adhesion studies. In this work discs were prepared from different sizes of a hard polymer, their roughness parameters were evaluated and related to each other and to bond strength of a joint using two pharmaceutical coating materials.

Materials and Methods

Materials

The substrate was polymethylmetacrylate (PMMA) beads (BDH, England) and the adhesives were polyvinylpyrrolidone (PVP K90) from Fluka, AG, Switzerland and Hydroxypropylmethycellulose (Methocel E15) from Colorcon, Kent, UK.

Methods

Disc preparation

The beads as received were first fractionated using sieve technique. Fractions between 75 - 500 μm were used in this study. Different amounts of particulate particle size fractions of the beads were poured into a ten bored mould with 12.8 mm diameter and 4 mm deep, designed for this particular work (Figure 1).
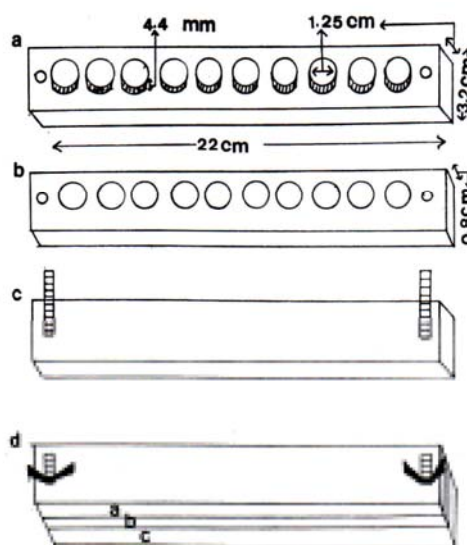

Figure 1. Mould for sintered discs preparation
a = upper part made of Aluminium
b = middle part made of brass
c = aluminium base
d = the assembly of the whole mould

It included two screws in the two sides to retain interparticle bonds during fusion in oven at 141° C (the nearest temperature to softening point of the polymer). The screws were tightened every 5 minutes to ensure contacts between beads. Using different amounts of particulate fraction sizes of beads insures particular porosities. The porosities were checked by calculation the dimensions of the discs and the true density of the polymer. The porosity values were the mean of five determinations.

Joint preparation

Five μl of adhesive solution (20%) was placed onto the centre of the discs using micropipette (Lubindustries) and a similar disc was then put leaving a free overlapping of 1 mm by aid of a mould. 100 grams weight was then put onto the assembly for 10 seconds to ensure a constant force for binding and an even spreading of the adhesive.

The bond area was observed to reject any probable an uneven spreading and/or undesirable bonds diameter formed between the two discs. The specimens were oven dried at 60° C for three hours, conditioned in 66% RH using dessicator contained saturated sodium nitrate solution (18) and then tested immediately at ambient temperature. This relative humidity was selected based on optimization experiment (19).

Shear testing

The specimens were tested using shear tester (DLE Direct shear apparatus) supplied with a bar consisting of strain gauge calibrated for a special force range (Figure 2).
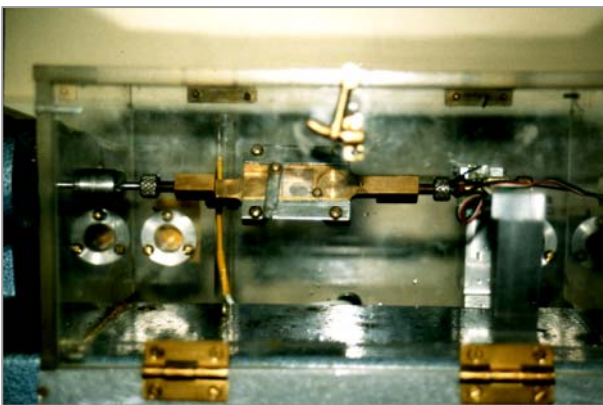

Figure 2. Assembly of bond strength testing included strain gauge.

Ten specimens were tested for each experiment and averaged and calculated for bond strengths using:

$$\sigma = \frac{2F}{A} = \frac{2F}{\pi r^2}$$

Where σ, F, A, and r are the strength (MPa), force (Newtons) at the failure point, the bond area (Cm^2) and radius (Cm) of the bond respectively.

Roughness determination

The texture of the surfaces was quantified on ten individual discs using Surface Texture Measurment Instrun (Model Surcom 110A A.M.S., Leicester, England) and 5 mm traverse length with 0.8 mm cut off. The mean and standard deviation of the R_a, Rt, Rtm and R_p, as explained before, of all measurements were taken across the diameter of the discs by a small computer connected to the instrument.

Scanning Electron Microscopy (SEM)

The surfaces of the particulate bead sizes PMMA were attached to a brass base by colloidal silver drag then left to dry on a disc holder. The assembly was then mounted in the gold coater machine for two minutes. The specimens were examined with scanning electron microscope.

Different magnifications were used to give suitable pictures on the monitor (Figure 3, 4).

Results and Discussion

Substrate considerations

PMMA beads were chosen as a model particulate bond system to study the adhesion because of several factors as followings:
1. It is insoluble in the binder solvent *i.e* water; therefore binding agents form inters particulate bonds without any dissolution and recrystallization of substrate material.
2. It is available in relatively regular sphere with a wide range of bead sizes.
3. It has intermediate surface energetic characteristics among polymers (20).
4. It is transparent which is important to observe and check the bond area to calculate the bond strength accurately.

5. It is relatively resistant to deformation and softening up to 60°C and keeps its integrity during testing.

In this study the effect of main variable macroscopic parameter of the substrate on bond capability, roughness, was considered.

Roughness consideration

It is well known that roughening a substrate can exert a positive effect on joint strength by increasing surface areas and providing interlocking mechanism for binding (21). Also this parameter could improve spreading by capillary forces mechanism (22).

Fractions of the PMMA beads were selected on the basis of the real adhesion science in pharmaceutical field that is using particle sizes less than 500 µm. On the other hand, beads of higher than 500 µm particle

sizes resulted in flattening surface during disc making (Figure 3) which makes ambiguous interpretation and is not the case in this study. Table 1 shows all roughness parameters measured and/or calculated. As could be seen, all parameters up to 500 µm are increased, uniformly as particle sizes increased indicating uniform distribution of the particle through out the discs mass.

For sizes higher than 500 µm the R_a, as defined above is not significant because the surface of the particle were flattened during discs making. As the table indicates, there is an excellent relationship between this parameter with particle size and there is no appreciate changes observed of this parameter for 500 µm and higher (Figure 3, 4). This implies the fully symmetrical mechanism of the system.

Table 1. Surface roughness parameters of sintered discs prepared from different particle sizes of PMMA beads and at different porosities.

Particle size (µm)	Porosity (%)	R_a	R_{max}	R_t	R_z	R_{tm}	R_{max}/R_t	R_{tm}/R_a
Particle size and related roughness parameter								
75-90	16.5	3.5	26.5	30.1	21.8	21.5	0.88	6.23
90-125	16.1	4.1	30.2	31.9	22.9	23.9	0.85	5.22
125-180	18.6	7.7	45.0	53.8	38.9	40.1	0.83	5.23
180-250	17.2	9.4	61.8	73.4	47.8	47.4	0.84	4.89
250-355	18.8	16.3	90.9	100.1	82.6	79.9	0.91	4.89
355-500	17.6	19.4	126.0	136.0	89.8	93.1	0.92	4.80
500-710	18.1	25.5	176.1	170.0	112.9	112.0	1.06	4.40
710-1000	18.4	25.1	---	178.6	---	112.1	---	4.47
Porosity and related roughness parameter of 90-125 µm fraction								
90-125	12.0	4.1	28.1	31.1	24.1	24.6	0.90	6.02
90-125	16.4	4.1	30.2	31.9	22.9	23.9	0.85	5.22
90-125	20.2	5.3	34.7	37.3	28.1	28.1	0.93	5.30
90-125	23.7	6.3	36.6	42.9	32.2	32.9	0.85	5.22
90-125	26.2	6.5	40.8	43.9	34.0	34.9	0.93	5.25
90-125	29.3	7.6	50.7	55.1	40.2	39.2	0.92	5.15

Tabel 2. Bond strength (mpa) of two adhesives /sintered discs system.

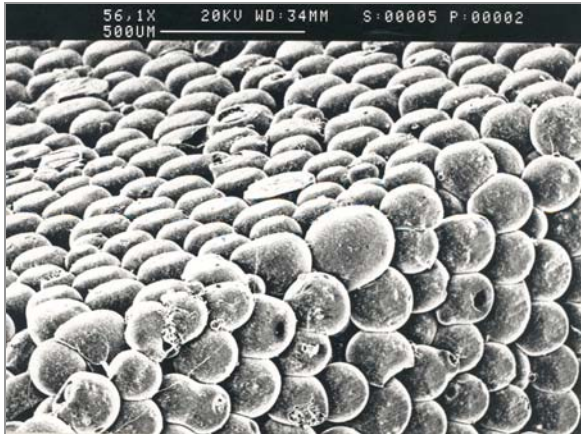| Particle size (µm)	Bond strength (Mpa)	
	PVP K90	HPMC E15
75 – 90	2.60 ± 0.37	5.72 ± 0.81
90 – 125	1.25 ± 0.31	4.40 ± 0.41
125 – 180	0.41 ±0.22	3.65 ± 0.25
180 – 250	0.22 ± 0.12	1.25 ± 0.34
250 – 355	0.26 ± 0.15	0.95 ±0.19
355 – 500	0.25 ± 0.12	0.55 ±0.19

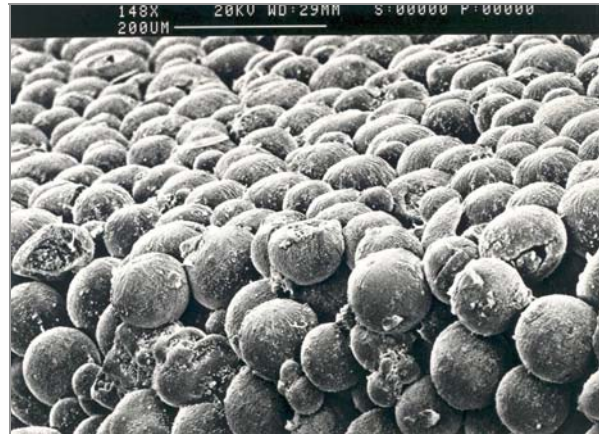Figure 3. Scanning Electron Microscope (SEM) discs surface made from 500±180 µm bead sizes of PMMA.

Figure 4. Scanning Electron Microscope (SEM) discs surface made from 200±35 µm bead sizes of PMMA.

Heating time for discs making

Different heating times of 5, 10, 15, 20, 25 and 30 minutes were conducted to retain fusion with appreciate flattening with screwing for each time. The heating time of 20 minutes was the best for suitable discs making. More and less heating time resulted in flattened and/or weakness of bonds between the beads at discs surface respectively. This was attributed to the more or less fusion among the beads in the mentioned temperature.

Effect of surface porosity on roughness parameters

Values of roughness are indicated in Table 1 which has been defined previously (10). As could be seen in the table all parameters amongst them R_a and R_{tm} which are more important, were uniformly increased as the porosity increased except the last column that is the inverse value, indicating the uniformity of the surface and the high reproducibility.

The values for different porosities of a particular particle size (90 - 125 µm), the second row group in the table, as expected, showed that increasing porosity as a result of higher distance from peak to valley is more for the non- homogeneity of the surface. Minimum porosity, beyond which no effective decrease in porosity has been

detected, was 12%. This might be attributed to closing of the voids in the discs surface during the heating process.

For this reason, we used the intermediate porosity between 16.5%-18.4 % in the above study, which did not have surface homogeneity but had flattening topography, while neither of them represents the curvature of the spherical particles. So only the particle size of less than 355 µm is reasonable for this model.

Effect of surface roughness parameter on bond strength

Figure 5 shows the effect of different discs types made from different particle sizes of the polymer, on bond strength of the adhesives under study. As could be seen the two adhesives clearly resulted in same trend of decreasing bond strength with increasing particle size. This may be due to fewer surfaces provided for bonding. As mentioned above, flattening the curvature of the particles at the surface also resulted in fewer surface provided for the bonds and less interlocking – mechanical mechanisms for bonds therefore resulted in weaker bonds.

Effect of surface porosity on bond strength

Increasing bond strength with increasing porosity for HPMC plasticized with glycerol using a peeling method was shown (23-25).

In fact all the authors related the compression forces of tablets to the adhesion as a result of different roughness, fracturing or flattening of the surface induced by punch and cohesion strength of the substrate. But in this present study, the fracture of the particles which occur during compression was avoided, the most ideal and defined shape, sphere introduced and the roughness correlate more precisely with porosity.

On the other hand it is well known that bond strength is highly related to the surface area. With constant area resulted from 5 µl adhesive solution, increasing particle size resulted in less effective area for bonds and in turn lowering bond strength (Figure 5).
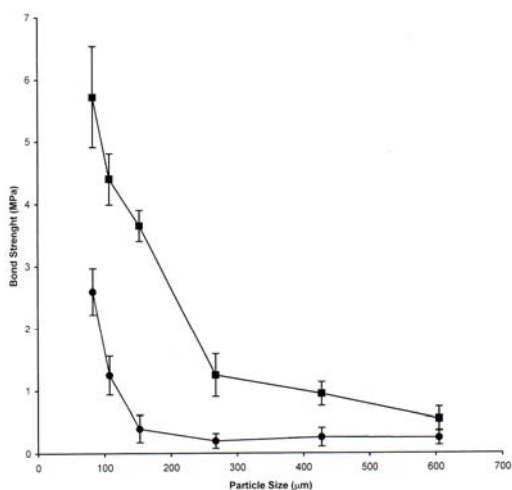

Figure 5. Effect of particle size of PMMA made as discs on the bond strengths of HPMCE15 (■) and PVPK90 (●).

This effect is not significant beyond 355 µm size due to flattening of the surface during discs making as mentioned above. The high standard deviation associated with the small particle size may indicate higher randomizing of particle arrangement at discs surface but this is not the case because the roughness parameter showed an excellent trend with them. So the only option remains might be the weakness of cohesiveness within the surface that was not withstanding to high stresses during testing and split at the failure point. Comparing these results with those indicated for smooth surface of PMMA (19) showed that although PVP gave stronger bonds than HPMC but not necessarily gives the same results with non-smooth interface. This may be due to the lower viscosity of PVP which causes more penetration into the sintered discs and less polymer available between the two discs or the stronger mechanical properties of HPMC E15 than PVP K90 which resulted in stronger bonds.

Conclusion

In conclusion it can be said that this model is a suitable for studying the effect of roughness on mild adhesives, pharmaceutical binders, providing that the substrate should have enough strength to withstand testing by means of adjusting optimum porosity. Also roughening the surface is more important than surface energy for bonding.

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