RHEOLOGY OF FOOD, PHARMACEUTICAL AND BIOLOGICAL MATERIALS WITH GENERAL RHEOLOGY

Edited by

R.E.Carter

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Proceedings of the Annual Meeting of the British Society of Rheology, University of Warwick, Coventry, UK, 12–15 September 1989

Preface

This book contains the proceedings of a conference organised by the British Society of Rheology from 12 to 15 September 1989, at the University of Warwick, UK. With the exception of myself during my first organisational visit, no other delegates tried to find the University of Warwick in or near the city of Warwick, for the campus is, in fact, in the southern suburbs of Coventry.

The conference title might, at first sight, seem to cover rather a wide range of industries and, indeed, disciplines. This was deliberate, since it had come to the notice of the Council Members of the British Society of Rheology that many industries were experiencing similar rheological problems. The meeting was thus formulated to bring together workers from different fields and callings. As can be seen from the variety of subject-matter for the papers, this target was successfully hit. Additionally, eight rheometer manufacturers exhibited their wares outside the lecture theatre, which provided a useful means of exploring some practical rheological problems experienced by the delegates.

The conference programme ran for two full days and one morning. There was much lively discussion after each paper, without exception, such that the chairmen had to curtail questions to keep to the timetable. Discussions were observed to carry over into the bars and lounges of the University on each available opportunity.

It was a pleasure to have present at the conference the first two recipients of the Scott Blair Scholarships. Mr Alex Speers from the University of British Columbia presented an excellent paper on the rheology of yeast suspensions. Mr Anthan Nithiananthan became the second Scott Blair Scholar when he received the first Pergamon Biorheology Scott Blair Scholarship. These awards were instituted to commemorate the founder of the British Society of Rheology, Dr G. W. Scott Blair, who passed away in 1987. The awards are made to second-year PhD students primarily to support liaison with European rheologists.

Dr John Benbow was presented with the Society's Annual Award for his services to rheology and to the Society. Having been a past President and my predecessor as Honorary Secretary, the award was very well deserved.

The conference dinner presented several practical rheological problems. This was because the dinner took the form of a mediaeval banquet in Warwick Castle, and delegates found that they had to drink their broth without the aid of a spoon, and eat their meat without the aid of a knife. One delegate who was 'volunteered' to taste the sauce (in case of poisoning) acquitted himself well with an impromptu impression of Richard III!

I would not be doing my duty if I did not conclude these opening observations with a sales presentation for the British Society of Rheology. This is a registered charity with the aims of bringing together rheologists and of promoting rheology as a science to the public at large. The Society was founded in 1940, and the Golden Jubilee Conference is scheduled for September 1990 in Edinburgh. For a small annual subscription (currently £6.00), members each receive four copies a year of the Society's *Bulletin*, detailing especially news of meetings both at home and abroad, and of *Rheology Abstracts*, which contain abstracts from most fields on matters rheological. Anyone interested in joining the Society is invited to contact me in the first instance.

Finally, I should like to thank my co-organisers and my staff. Dr Geoff Brownsey and Dr Ralph Oliver assisted in the scheduling of the papers. Julia Sutton and Paul Weaver, both of Carter Baker Enterprises Ltd, coped with the vast amount of paperwork involved in the conference administration. And, of course, I must thank the contributors and delegates, without whom there could have been no conference at all!

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Contents

STRUCTURE AND MECHANICAL PROPERTIES OF MODEL COMPOSITE FOODS

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ABSTRACT

The role of fat in cheese analogues on failure and small deformation properties and on fracture mechanisms was assessed. Oil inclusions softened and weakened the composite while solid fat hardened and strengthened it. If the oil droplets were bound to the matrix, their effect on composite behaviour was similar to that of solid fat. Oil in the free droplets was readily released on deformation or fracture, enabling it to lubricate movements involving the matrix.

The fail stress and fracture mechanisms of heat-denatured protein gels containing solid glass spheres, oil droplets and porous cross-linked dextran spheres were investigated. The composites containing glass spheres and oil droplets fitted a strong filler-matrix interaction model whereas those containing dextran spheres fitted a weak interaction model. The fillers had a marked effect on the distribution of protein in the matrix. Clean glass spheres adsorbed it, hydrophobically-coated spheres were concentrated in holes in the matrix, and dextran spheres produced an ordered structure in the matrix. These differences were reflected in the fracture mechanisms of the composites.

INTRODUCTION

The major interest in mechanical properties of particulate composites has generally been in relation to their use in the construction and vehicle industries. For these, the strength and toughness is paramount and fracture must often be avoided. The inclusion of rubbery particles, especially if they adhere well to the matrix, has a desirable toughening effect [1]. Rigid inclusions have less predictable effects and liquid droplets are of little interest.

For food composites, the requirements are different. Most important is a desirable texture or mouthfeel. The perception of this normally involves compressing, shearing and multiple fracturing. The handling of food during processing and preparation, which often involve cutting the end product, and during transport, are also important. These considerations dictate the mechanical properties which are useful to measure and interpret.

The mechanical properties of a composite food must depend on the composition of each phase and its volume fraction and distribution, and the extent of interaction between phases. To study each variable separately, we need reproducible composites in which composition, particle size and interaction between particle and matrix can be varied. This can be achieved readily by using model composites.

This paper is concerned with two types of composite, cheese analogues containing fat globules in a protein matrix and filled gels containing hard, semi-hard or liquid particles.

The first type of composite is typified by cheese. This is a viscoelastic solid tending to be inhomogeneous, which makes the usual simple compression-like tests difficult to interpret [2]. However, the composition of the matrix and concentration of fat in a group of 62 cheeses ranging from hard to soft have been shown to be related to their abilities to flow under pressure [3]. Recently, fracture mechanics has been applied to Gouda cheese so that the roles of individual components in fracture can begin to be elucidated [4]. A problem experienced in this work was the appearance of internal cracks in the sample early in the deformation process. This can be overcome by using a less brittle material such as a processed-type cheese.

Paté-type products are examples of the second type of composite. We know of no relevant work on such products, perhaps because of difficulties in reproducibility. However, work has been done on model systems of this type. Ross-Murphy & Todd [5] have studied the effects of size, shape and volume fraction of filler on the tensile failure of gelatin gels containing glass particles and have developed theoretical explanations of the results. Most other work has been concerned with small deformations. In gelatin gels, semi-hard fillers increased plasticity [6] and caused reinforcement [7]. The incorporation of small droplets of oil into heat-set whey protein gels made them firmer [8].

The present work is preliminary and extends some on related materials described earlier [9]. It is concerned with relating characteristics of the particulate phase and interactions between the particulate and continuous phases to the mechanical properties of the composite. Although small deformations are given consideration, the main interest is in the fail strengths and failure mechanisms.

MATERIALS AND METHODS

Materials

Sunflower oil was purchased locally, Hycoa 5 was obtained from Loders & Nucoline, Silvertown, London, U.K. and the various grades of Sephadex cross-linked dextran spheres were from Pharmacia Fine Chemicals AB, Uppsala, Sweden. Other materials were as described elsewhere [10, 11].

Preparation of composites

Cheese analogues and composites containing glass and corn oil in a heat-denatured whey protein matrix were prepared as described elsewhere [10, 11]. Sephadex particles were preswollen in the gelling solution prior to gelation.

Mechanical tests

Most tests have been described in full elsewhere [10, 11]. For cheese analogues, maximum stress and work to maximum stress were determined in compression at 8.3 $mm.s^{-1}$, work of fracture was the energy required to form two cut surfaces at 0.083 $mm.s^{-1}$ and Young's modulus and stiffness were measured in the initial stages of compression at 0.083 $mm.s^{-1}$ and 0.033 $mm.s^{-1}$, respectively. For filled gels, the stress at failure, was determined in compression at 0.83 $mm.s^{-1}$. Three-point bending tests (span 25 mm) were carried out on cylinders (length 50 mm; diam. 15 mm.) at 0.17 $mm.s^{-1}$.

Scanning Electron Microscopy

Fracture surfaces of cheese analogues were frozen, etched and examined as described elsewhere [10]. Fracture surfaces of gel composites were examined as described elsewhere [11] after dehydration and critical point drying.

RESULTS AND DISCUSSION

Cheese Analogues

Our main interest in studying cheese analogues was to elucidate the role of fat. This is undoubtedly essential to the mouthfeel, but may also influence properties important in transport and packaging. Mechanical properties relevant to mouthfeel were assessed from fracture characteristics at as high rates of application of force as possible. Those relevant to structural integrity were deduced from small deformations at slow speeds.

In the work varying fat concentration and fat hardness, the fat was emulsified with a neutral detergent before incorporation into the protein matrix, minimising the interaction between the fat globules and the matrix. However, in one experiment, the fat was emulsified with sodium caseinate. This would cause significant interaction between the fat globules and the matrix, enabling this to be compared with the minimal interaction case.

Unfortunately, all composites did not have identical structures. although the fat globules were all approximately spherical, they tended to be larger in the composites containing lower fat concentrations.

Effect of butterfat concentration: As the concentration of butterfat in the composite increased, the fracture properties measured in compression decreased. This indicates that fat globules weakened the composite, suggesting that the fracture passed through or round the globules, as shown for Cheddar cheese [12].

The work of fracture measured by cutting also decreased with fat concentration. Examination of frozen and etched surfaces by SEM showed that fat had been smeared over the cut surfaces (Fig.1), the area of smeared fat increasing as the fat concentration in the composite increased. This shows that fat lubricated the passage of the wire. Thus, the easier cutting at higher fat concentrations is probably related to both the mostly liquid nature of butterfat at room temperature (70-80%) and the lubricating effect.

The deformation properties behaved differently. They tended to increase with the fat concentration at low concentrations decreasing again at higher ones. This unexpected observation may relate to the change in globule size with fat concentration or to the crystallinity of the fat.

Effect of fat hardness: The effect of the physical state of the fat was investigated by replacing the butterfat in the composite by