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A method to measure the fusion strength between expanded polystyrene (EPS) beads

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Cellular polystyrene (EPS) is the most commonly used cellular thermoplast whose main applications are insulation and packages. One of its new applications is core material in building elements, and this poses higher requirements for strength. This is particularly evident in self-supporting roof elements. This study presents a method for determining the fusion strength between beads in cellular polystyrene and the dependence of this strength on processing. This method has also enabled us to determine the adhesion of cellular polystyrene beads to other materials, such as glass fibre, and it allows measurement of the fusion strength between EPS beads without the influence of porosity. Fusion strength was found to have a characteristic behaviour. It has an absolute upper limit, and fusion forces approximate this limit asymptotically as heating time is prolonged (this increase is dependent on the energy content of the steam).

1. Introduction

There are various ways to measure properties of materials. The most common way is to determine the properties of a ready-made product. The drawback of this method is that it makes it very difficult to distinguish the relative effects of different factors. This is why it has been necessary to start developing more efficient methods. The first stage has involved standardizing methods, conditions and test pieces. In the second stage we have elaborated "microscopic" methods as pure as possible for measuring the effects of one factor at a time, independently of other external factors.

Cellular polystyrene is a material whose properties are typically dependent on many factors, such as raw material, processing and internal structure [1]. It is manufactured by using external energy to expand polystyrene beads soaked with propellant and doped with core-forming particles. External energy is normally brought into the material in the form of hot saturated water steam. Cellular polystyrene is processed either in a continuous process or in large block moulds, and this causes a large dispersion in properties.

The structure of cellular polystyrene can be analysed at two levels, as is evident in the scanning electron micrograph of Fig. 1. Cellular polystyrene consists of beads sintered together and empty places between them. The fusion strength between beads determines the real strength of cellular polystyrene. The beads themselves consist of a cellular structure, which is normally closed and very regular. The density of this structure varies greatly, but this is due to inhomogeneity in the raw material and/or in the cell formation process [2]. Therefore, a method which studies the sintering of beads reveals the real service durability of cellular polystyrene.

2. A method for measuring fusion strength

In this study we have quite simply developed a method for producing a fusion surface between two beads under controlled conditions and testing its fusion strength. For this reason the bulk of the work has consisted of developing and building appropriate equipment.

Fig. 2 shows a diagram of a specimen comprising two beads and a photograph of the mould that was used to produce the specimen. We have managed to build a mould that accurately controls expansion and the area of fusion surface.

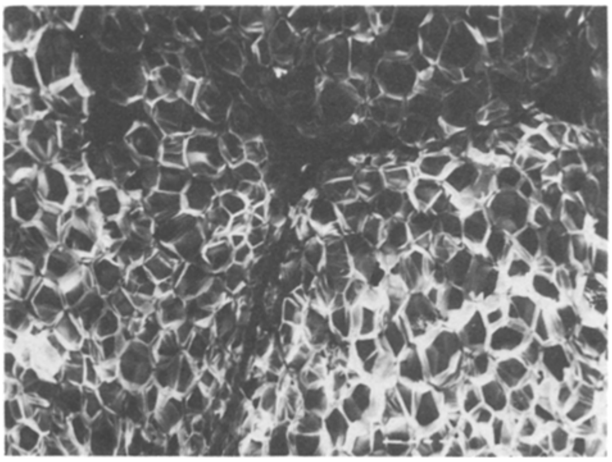

Figure 1 A scanning electron micrograph of the structure of expanded polystyrene.

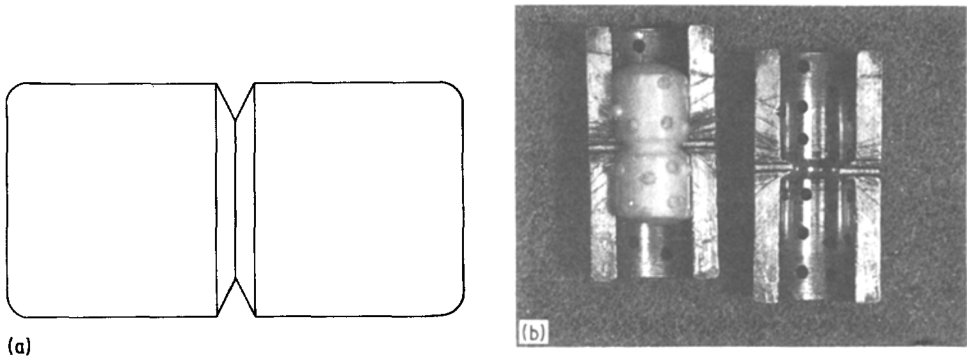

Figure 2 (a) A diagram of the two-bead specimen, and (b) photograph of the mould used and the specimen.

In the second stage we have built a laboratory-scale processing device which allows accurate variation of all normal processing parameters. Fig. 3 shows a diagram and a photograph of this equipment. It allows exact control of steam pressure and temperature and of the duration of the steam treatment; if necessary, the equipment can be evacuated and dried by blowing.

The last stage is testing the two-bead specimens. For this purpose we have had to develop a method for attaching the specimens to pulling jaws and to build suitable jaws by which the fusion surface between the beads is exposed to pure tensile stress. A diagram of the method is shown in Fig. 4, which also shows a photograph of the test arrangement.

3. Experimental procedure

As coating may have unknown effects on fusion strength, the raw material was uncoated. Coating is normally used to avoid undesired fusion of beads during pre-expansion. An appropriate coating, such as zinc stearate, decreases fusion between beads and guarantees undisturbed pre-expansion.

Since the dependence of strength on density must be taken into account, a narrow density distribution of the beads should be set. The maximum diameter of beads is limited to 6 mm (this is the inner diameter of the mould, the raw beads must be screened to fit this volume after expansion). The EPS beads are very close to spherical in shape (only when a bead grows very big does it lose its spherical form). The density of expanded beads can be measured quite simply from the volume of the globe. Of course, the weight of a bead is not constant since a great deal of the blowing agent is lost during processing. The total blowing agent content is about 6%. In this study we assumed that the blowing agent content did not vary between beads, since pre-expansion and ageing were identical. The raw beads were deep frozen, and the required amount of them was brought to room temperature to warm up before pre-expansion. This was necessary to ensure that the blowing agent content would not differ between beads. The beads were screened to keep the unexpanded bead size fraction between 2.5 and 2.6 mm. The final diameter of the beads is 6 mm, and their density is thus $81.3(\pm 5.3)\,\mathrm{kg\,m^{-3}}$.

Pre-expansion was accomplished by boiling water; this method allows easy control of the process. At first we measured the dependence of expansion on time to

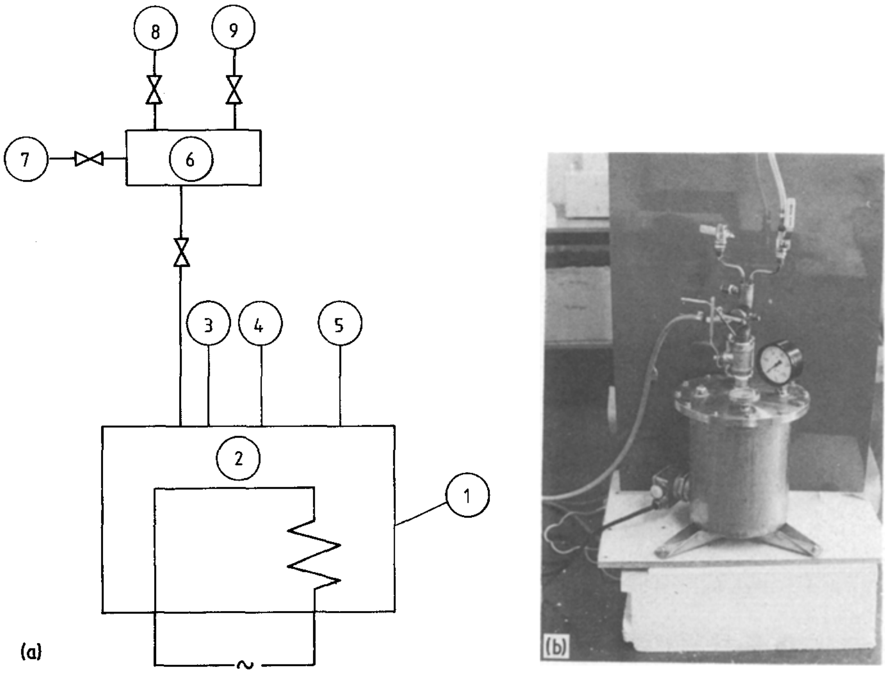

Figure 3 A diagram (a) and a photograph (b) of the laboratory-scale processing equipment used. 1, pressure vessel; 2, heating element and water; 3, pressure regulator; 4, thermocouple; 5, pressure meter; 6, specimen chamber; 7, air inlet; 8, air outlet; 9, vacuum pump.

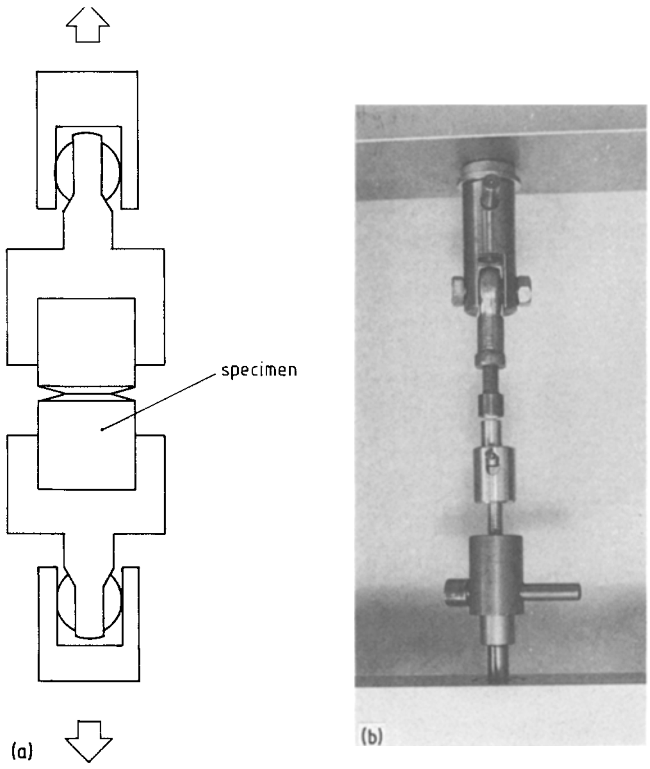

Figure 4 A diagram (a) and a photograph (b) of the tensile testing grips of the two-bead specimen.

determine the optimal duration of expansion. The ageing time between pre-expansion and moulding was constant.

Moulding took place in three separate stages: during the first stage a steam flow was directed through the mould chamber and mould. At first the steam clears air away and heats the mould and the beads. The heat exchange between steam and the specimen is effective. At the beginning of the second stage the outlet valve is closed and the pressure reaches the same value as in the steam generator. Upon entering the third stage the outlet valve is opened and the pressure in the mould chamber begins to decrease. Immediately after the third stage, pressurized air is blown into the mould chamber to cool the specimen down.

We altered two variables: steam pressure and the time during which the steam flowed through the mould chamber. The duration of the second and the third stage was held constant at 5 sec. Steam pressure was varied between 0.3 and 1.5 bar.

The specimens were left to age for 2 weeks to decrease the blowing agent content. The blowing agent (pentane) is a plastizer and decreases strength. The tensile strength was measured by a universal material testing machine JJ Lloyd T5003.

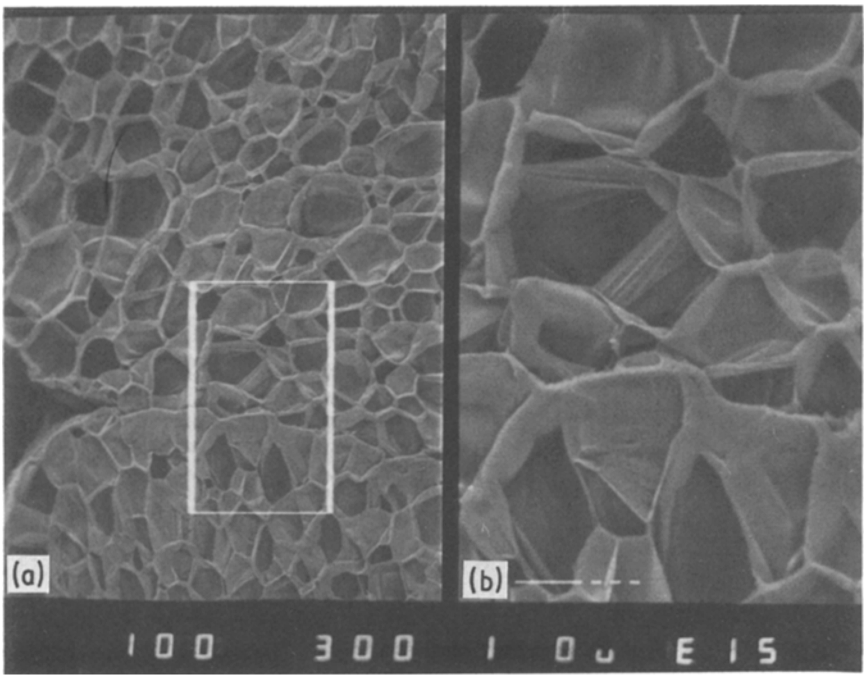

Figure 5 A scanning electron micrograph of the fusion surface between two beads in a specimen. (a) × 27, (b) × 90.

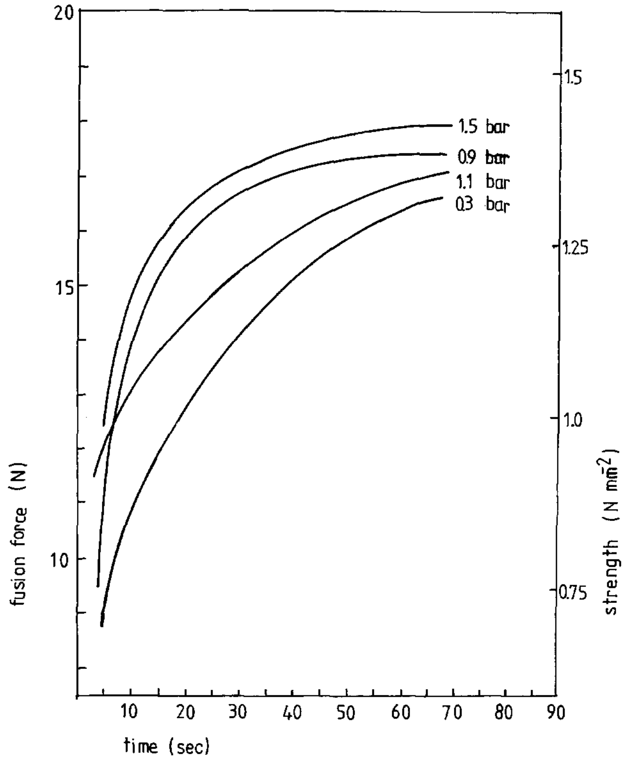

Figure 6 The first results as measured by the micro-mould method. Steam pressure 0.3, 0.9, 1.1 and 1.5 bar.

4. Results

Fig. 5 shows a scanning electron micrograph of the fusion surface between two beads. The fusion between beads was complete. Specimens always ruptured along the fusion surface. The area of the fusion surface was 12.57 mm^2. Fig. 6 shows the correlation between rupture strains and heating time (heating time means here the duration of the first stage when steam flows through the mould chamber). Steam pressures were 0.4, 0.9, 1.1 and 1.5 bar. All values presented are mean values of several measurements. There seems to be an absolute upper limit to fusion strength. At low steam pressures the fusion strength slowly approximates the maximum when heating is prolonged. If steam pressure (and temperature) is high the fusion strength jumps abruptly close to the maximum, and the increase in strength during prolonged heating is asymptotic.

5. Conclusions and applicability of the method

This study reveals how fusion strength depends on heating energy. A high steam pressure (and temperature) guarantee complete fusion between EPS beads – heating time is not as simple as that. A specimen which contains a great number of beads has to have minimal porosity to reach maximum strength. This phenomenon leads to other problems and applications, however, which are not discussed in this study. To gain a better understanding of the moulding process and the properties of EPS it is necessary to make a distinction between fusion strength and the area of the fusion surface; the micro-mould system was constructed for the study of the former. On the basis of the first results the micro-mould system seems a promising procedure for the analysis of mechanical properties of expanded polystyrene, and it also helps us understand the processing of EPS in greater detail than before.

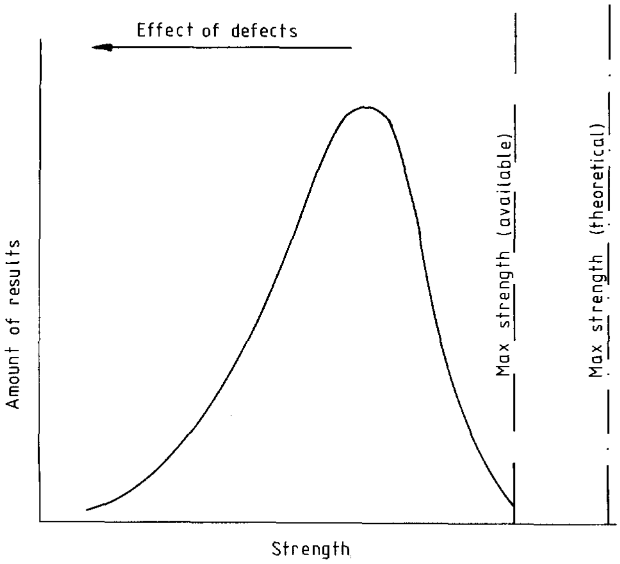

Figure 7 The distribution of the strength values and their relations with the experimental and theoretical values.

The dispersion of the results is relatively large, but this is typical of microscopic methods in general. Part of this dispersion can be eliminated by using large test series and concentrating on the covering curve drawn on the basis of maximum values. We can normally expect that the results are distributed between the theoretical value and the maximum attainable value as shown in Fig. 7.

On the basis of our results we may conclude that this method measures the adhesive fusion strength between beads of cellular polystyrene. The method is also sensitive enough to reveal changes in normal processing parameters as changes in fusion strengths measured.

The tests where this method was applied for measuring the adhesion between glass fibre and cellular polystyrene by placing a fibre on the fusion surface between two beads, proved that the method works. We could not obtain the bond strength between glass fibre and cellular polystyrene, since we used uncoated glass fibre and the steam used for processing immediately formed a film of water on its surface, thus preventing the creation of an adhesive bond between polystyrene and glass.

References

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