VIEWPOINT

The relationship between polymer engineering and glass technology

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What has polymer engineering in common with glass technology? Because of the frequent blurring between polymer engineering and glass technology disciplines, and recent significant industrial developments and advancements in the field of materials science and engineering (MSE) by large glass and ceramic industries such as Corning Inc., the important relationship between polymer engineering and glass technology needs to be rationalized. Currently, most MSE departments in universities in the USA are essentially reoriented metallurgical and ceramic departments, with perhaps one or two faculty members specializing in polymers. As a former project engineer with Corning Inc., and currently the only polymer engineering faculty member of the newly reorganized MSE Department at Iowa State University, I will attempt to answer the above question and to place the subject of polymer engineering in the context of glass technology as practiced in industry, and within the framework of the MSE discipline in general. First, I will give an all-embracing definition of polymers, then, relate it to glasses and, finally, mention current and future activities of polymer engineering departments in the glass–ceramic industry.

Fundamental aspects

The word 'polymer' literally means 'many parts' (from the Greek *polus*, meaning 'many', and *meres*, meaning 'parts'). Thus, 'polymer' is used to embrace all those materials whose molecules are made up of many units, either single atoms or, more likely, a small group of atoms in a state of chemical combination[1]. Metals, ceramics and crystalline forms of smaller molecules are polymers too, in the broadest sense of the word. According to Treloar[1], the so-called 'plastic sulfur' (obtained when molten sulfur at a suitable temperature is poured into cold water) is a good example of a polymer whose units consist of a single S-atom. In this state, sulfur has typical polymeric rubbery properties in the sense that it is soft, highly elastic and translucent. These properties are dramatically different from those of the ordinary crystalline (rock) sulfur raw material[1]. This ability to change properties by using physical or chemical methods is one of the underlying bases of polymer engineering. Polymer engineering may be defined as that branch of engineering that deals with the study of the physical and chemical properties of polymers and of the processing of polymers, including plastics, rubbers, films, fibers, coatings and adhesives, into useful engineering articles of various shapes and sizes.

In contrast to polymers, inorganic glasses, such as window glass, are based on inorganic (mineral) materials such as silica and boric oxide (B_2O_3), together with oxides of sodium and calcium. These inorganic glasses are not true polymers in the sense of possessing permanent molecules of chain-like form, but they do form a kind of temporary network structure in the process of cooling down from the molten state[1]. Therefore, they are closely related to polymers, and owe their glassy properties to similar basic factors to those that are responsible for the glassy properties of organic polymeric glasses (such as Plexiglass™ and Styron™). Therein lies the important interrelationship between polymer engineering and glass technology. In addition, pure glasses are typically brittle materials that are very sensitive to catastrophic propagation of surface flaws during service. This is why relatively tough and low-temperature polymers are blended with glass in commercial products (e.g. Cortem™) to eliminate or reduce the problem as well as to serve as processing aids for the brittle glass. Metals, too, are often processed in conjunction with organic polymers to make complex shapes having excellent magnetic and electrical properties, among other desirable functional engineering design requirements. Another major impetus for using polymers in conjunction with other materials in technologically demanding engineering situations is that, unlike metals and ceramics, the molecular structure of organic polymers can be changed relatively easily.

Technological aspects

The important synergy between glasses and polymers was recognized by the glass–ceramic industry in the late 1960s and led to the creation of polymer engineering departments within the industry's core technology groups. Typically, the personnel in these departments comprise highly skilled professional engineers (polymer/chemical engineers), technologists and chemists, with multidisciplinary technical backgrounds, working together to ensure that the polymer engineering needs of the company are met in a timely manner. In addition, the personnel are always on the lookout for opportunities to add value to existing products and businesses, to keep up with outside competition and to maintain a leading-edge technology in materials engineering. As an example, the polymer engineering department at Corning Inc. has provided support services to internal customers in the cross-functional engineering areas of protective polymeric coatings for liquid crystal display glass, consumers' decorating businesses, fiber-optic coupler adhesives, composites, glass–polymer melt blends, Celcor™ (ceramic substrates for automotive engine emission control), and television glass-sealing frit paste, to name but a few.

More recently, researchers at Corning Inc. have developed a new family of chemically durable zinc alkali phosphate glasses[2]. These glasses are typically based on P_2O_5, and they exhibit properties that are typical of organic polymers. For example, various advanced spectroscopy techniques were used to confirm that the structure of the polyphosphate glasses is chain-like, such as is found in organic polymers. Generally, the longer the chain length is, the more durable (water insensitive) the glass. Close to their melt processing temperature (c. 400°C) and at high shear rates (typical of the processing operation), the melt rheology of the polyphosphate glass is viscoelastic, shear thinning, and exhibits strain-induced crystallization, as observed in organic polymers (Ref. 3 and J.U. Otaigbe, unpublished). Because of these similarities with organic polymers, polyphosphate glasses have been successfully melt-blended with high-temperature polymers [such as poly(ether ether ketone) and Amoco's Xydar™] to produce a new family of advanced glass–polymer melt blends (Cortem™) that are stiff (Young's modulus of 27.8 GPa or 4×10^6 psi), strong, dimensionally stable, injection-moldable, thermally stable at >300°C, and flame resistant. The polymeric nature of the glasses allows high glass loading in the glass–polymer blend (>75 wt% glass!) by using conventional plastic processing methods. Potential applications of these new materials are in aerospace, automobile, lighting, electrical and consumer areas.

Lastly, a major activity of polymer engineering departments in a typical glass–ceramic industry is in the area of rheological characterization, data interpretation and analysis of materials in both solid and liquid states. The use of the term 'rheology' (from the Greek *rheos*, meaning 'flow') implies that all matter responds to stress by flowing. The basic art of materials (e.g. glass and polymer) processing is concerned with forming the materials into desired shapes and fixing the shapes by such processes as cooling, crosslinking and coacervation. The timescale for these processes and material responses varies greatly, and must be known and controlled for product reproducibility. New requirements and products demand modifications and improvements in the art of materials processing. Therefore, it does not require much imagination to show that rheology should be of interest to the materials (glass or polymer) processor, scientist and engineer[4].

Concluding remarks

The foregoing discussion shows that polymers in their various forms of plastics, rubbers, films, fibers, coatings, adhesives and unique viscoelastic melts must be exploited if we are going to maintain a competitive edge in the ever-changing industrial world and its technology. One way to do this is to recognize the many similarities between polymers, metals and ceramics, and use these similarities in a synergistic manner to make significant technological advancements. Several Fortune 500* corporations are already doing this, but some US academic institutions are slow to respond to this unique synergistic advantage in the content of their MSE curricula. From both my industrial and academic hands-on experience, I believe that a unified MSE discipline will contribute significantly to the rapid development of this evolving field. Developing ceramic engineering, metallurgical engineering or polymer engineering separately would be very restrictive in real-world materials engineering situations, and MSE development without adequate emphasis on polymers would be hopelessly incomplete.

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*A ranking by *Fortune* magazine of the 500 largest corporations in the USA.

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