Plastic Foams in Prosthetics

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In prosthetics, as in many other fields, plastic materials were quickly adopted as soon as their usefulness was recognized, not just as a substitute for other materials, but also as a supplement in places where no other material would function as well. The plastics industry is comparatively young; not much headway was made until the start of World War II. Since then giant strides were made with the discovery of new polymers in chemical laboratories annd the improvement of fabrication processes. Everybody knows of the revolution the plastic fibers have produced in the textile industry. At first they were a poor substitute for natural fibers, but now they are in many cases superior in a number of physical properties.

Plastic foam has built a niche of its own in its short rise to prominence. Its many uses in industry would require pages to enumerate. In prosthetics the use of foam got a start about four years ago, when it was first utilized as a convenient substitute for wood. With the continued improvement of the material and perfection of better manufacturing techniques, foam is sure to find ever wider application in the artificial limb program.

It might be well now to pause for some technical explanations, lest some readers get confused by the term "plastic foam." Foam brings to mind to many people the soft, spongy material such as is used in upholstery and mattresses. That it is, but this is only one kind of foam. As manufactured today, foam comes in many different varieties and densities, running the entire gamut from very soft and flexible to quite rigid.

Plastic foams can be produced from different chemicals, such as polyurethane, vinyl, polystyrene, polyethylene, phenolics, silicones, epoxies, or chloroprene (neoprene). The raw material that is mostly used is polyurethane. Urethanes are based upon isocyanate resins. When isocyanates are reacted with "active" hydrogens such as occur in polyols—glycols, polyesters, polyethers, or castor oil, for example—they form addition polymers, among which is urethane. When a polyol, together with some water, a catalyst, and an emulsifier is mixed intimately with the required amount of diisocyanate, polymerization and gas-forming exothermic reactions proceed at the same time, yielding a gel structure in which the evolved gas is trapped. The cured material is a urethane foam.

The molecular structure of the polyol determines whether the urethane foam will be flexible or rigid. The most important factor in determining the rigidity of a foam is the hydroxil-rich compound used in its production, which group includes diverse chemicals such as the aforementioned polyols. It is not surprising to find such a wide spectrum of rigidity that is potentially available for these cellular products. Even within a certain type of rigidity it is possible to vary the physical properties. Thus, one can make flexible foams that are resilient and also flexible foams which have high energy absorbing properties. In addition, the density of each type can be varied from above 60 lb./cu. ft. to below 2 lb./cu. ft. Considering a "six pound" density foam, it can vary in resilience from a firm foam to a very soft one. The firm foam will support the weight of a man without crushing, whereas the soft one can be balled up by handling and will slowly return to shape in a period of minutes. It is seen, therefore, that polyurethane foam can not be regarded as a single entity, but rather as a broad class of materials from which it is possible to select individual foams to fit a desired application.

Foam, in its different forms, has many properties which make it desirable for use in artificial limbs. It is easily fabricated; it has a high strength-to-weight ratio; it resists wear; its shrinkage and resilience can be controlled; it resists bacteria and fungi; it can be made fire-retardant or self-extinguishing; it is easily cleaned and is not affected by soap, detergents and most solvents.

Flexible foam finds most applications in cushioning, as for instance in the Total-Contact Socket (Figure 1). Here a shaped pad is foamed inside

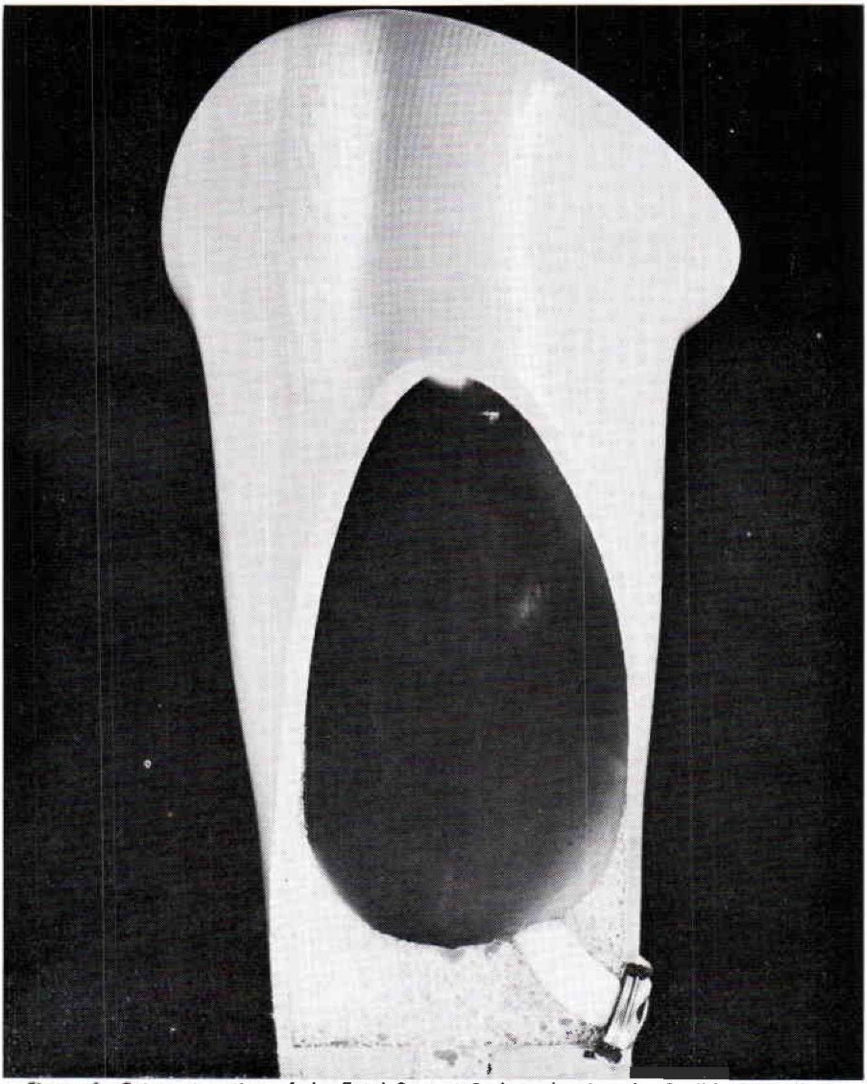


Figure 1. Cutaway section of the Total-Contact Socket, showing the flexible foam liner.

the socket, so that close contact is provided between the stump-end region and the soft socket bottom. During the weight-bearing phases of prosthetic use, the forces acting against the stump-end are compensated by the rather free compression of the foam material, providing an even distribution of contact. During the swing phase the intimate contact pressure is lessened but maintained, and by this alternating action a genuine massaging of the stump-end takes place, which works for improvement of the circulation in this stump region.

Another use is in the soft-wall socket. Here, the complete inner socket liner is made of flexible material, a construction which first of all allows the stump muscles to expand, aiding thereby the action of the muscle pump through the elastic counter-pressure of the socket walls; secondly, the pressure-sensitive bone contours are softly bedded in. This liner is part of a socket technique which often makes is possible to do away with the conventional thigh-lacer and mechanical joints for the below-knee prosthesis.

The ideal socket-liner should have varying degrees of flexibility; stiffer at weight-bearing areas, more flexible where only padding is desired. Also needed is a suitable coating that will do two things: provide a perfect cosmetic finish, and seal the cells. If the cells are open, the foam acts like a cheese grater on the stump. It is hoped that these problems will be solved before long.

As another example, in the polyester functional orthesis to aid persons with paralyzed hands and wrists, the layer of material next to the patient's skin is one-eighth inch foam. The foam helps eliminate the problem of discomfort from pressure over the bony prominences in the extremely atrophied hand where little muscular padding is present.

The ability of flexible foam to absorb energy or shock is put to good use in the SACH foot. Besides absorbing impact in the heel and simulating plantar flexion, the flexibility in the rest of the foot is designed so that it simulates normal toe break (Figure 2). When properly constructed, the foot will show little toe curl after millions of flexion cycles. It is readily molded to any shoe last desired; its fleshy feel is an advantage cosmetically.

Lately, shank covers for hydraulic legs are being made out of foam. These serve not only as a cosmetic cover, but also as a cushion to protect the mechanism. They can be pigmented to any flesh color desired, from fair caucasion to dark negroid. Flexible foam is also used in padding and fillers in other prosthetic and orthopedic appliances.

Rigid foam has found different but equally useful applications. Its most prominent use is in the substitution for wood. Wood was, and still is, used extensively in the production of sockets and shanks, feet, and as a filler material. Balsa wood is used as a filler between the ankle block and the below-knee socket because of its lightness. Willow wood, poplar, or basswood are used for the A/K socket because of their strength. At the present time, wood is still preferred over foam because the wood carving technique has been mastered by limbfitters, whereas the foam molding technique is still new. Also, wood is finished more readily than is foam.

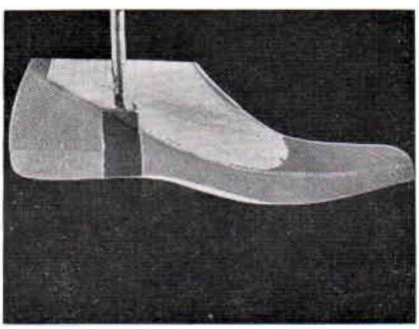


Figure 2. Longitudinal section of the Bock SACH foot. The three different foam layers of the sole, heel and upper foot are clearly seen.

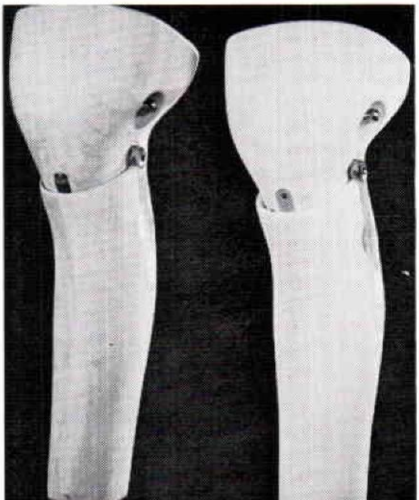
The strength of the foam in comparison with wood is still largely an unknown quantity. As is common to the general field of plastics, there is a paucity of physical data relative to the rigid foams discussed here. Most of the data have been obtained from core samples and, hence, may not be a realistic measure of the physical data desired. An approximate comparison is given in the following tabulation (properties of basswood, willow wood and poplar are somewhat similar):

	Basswood	*Balsa Wood*	*Rigid Urethane Foam*	
			Med.	*Low*
Density, lb./cu. ft.	23	8	23	8
Moisture content, % by weight of oven-dry specimen	5-12	12	1	8
Tension perpendicular to grain, max. tensile stress, lb./sq. inch	350	180	800	230
Compression parallel to grain, max. crush. stress lb./sq. inch	3800	2000	1200	230

These figures are taken from Wood Handbook 72, U. S. Department of Agriculture, and Modern Plastics Encyclopedia.

In general it can be said that, on an equal density basis, rigid foam is somewhat stronger in tension and considerably weaker in compression than wood. It therefore becomes necessary to reinforce the foam in areas under compression.

The advantage of foam over wood is that foam lends itself readily for mass-production, in contrast to the slow process of carving each individual wood shank or knee block. With a mold and the liquid resin material, the model can be readily reproduced in the factory. The mixing is done in batches as needed, and according to the density desired. In newer methods,



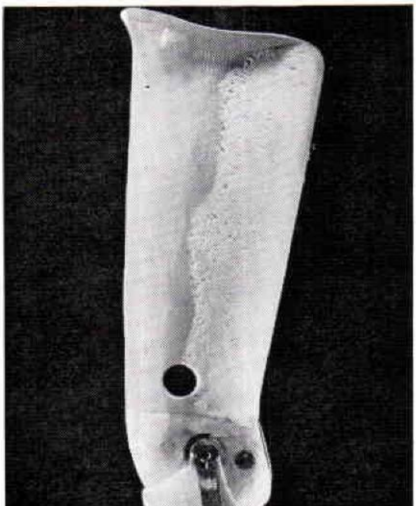


Figure 3. Bock Locking Knee Prostheses in wood (left) and rigid foam, side by side. Figure 4. Posterior side of socket built up with rigid foam to bring up to size. After relaminating the outside, there will be no telltale mark to show the alteration.

the "one-shot" polyether foaming system has contributed to production economies. Based on the use of a new combination of catalysts, this system eliminates much of the pre-mixing required in earlier methods and simplifies curing requirements. Foaming can be complete in as short a time as 3 minutes.

Another advantage is that foam will not absorb moisture, while wood has a tendency to do so. Wood has to be stock-piled, seasoned, and in certain areas dehumidified. With foam, the storage of two or three containers with the component mixtures is all that is required. If sufficient quantity is involved, the cost of the mass-produced foam article could be well below that of the wooden counterpart. If modifications have to be made, the same tools used for woodworking can be used on rigid foam. On such items as shanks and knee blocks, there is no problem with the cutting of the outer skin or coating since the final prosthesis must be plastic coated anyway. A commercial knee-shank system, done in both wood and foam, is shown for comparison, before coating, in Figure 3.

Rigid foam can easily be used as a filler to bring undersized limbs up to size, as shown in Figure 4. It is also used as filler in arm prostheses.

Foams, both rigid and flexible, lend themselves readily to application by spray technique. Internal-mixing guns give a uniform foam equal in properties to many machine-mixed foams. Applications such as impervious coatings, insulating, padding, and building-up of undersized parts, suggest themselves for this technique. All the potential uses have by no means been explored as yet in the field of prosthetics or orthotics.

As can be seen, plastic foam is quite a versatile material. Not all the problems in connection with it have been solved. Fabricating techniques need to be perfected, and closer control must be found for obtaining desired densities. Precautions must be taken in handling, especially in spraying, as the fumes act as an irritant to the mucous membranes. All in all, however, foam materials have taken a firm hold in prosthetics. Besides the many good properties of foam, the techniques for its use allow sufficient saving in labor to more than compensate for a higher material cost over the conventional materials such as wood.

Publications Received

The Division of Engineering and Industrial Research, Annual Report 1960-61, (National Academy of Sciences-National Research Council) Washington, D. C.

This well-written report describes many activities of the National Research Council in the field of Engineering and Industrial Research. Of special interest to readers of the *Journal* will be the report of the Committee on Prosthetics Research and Development, pages 149-158.

Copies of the publication are limited; it may be borrowed from the Headquarters Library of the American Orthotics and Prosthetics Association.