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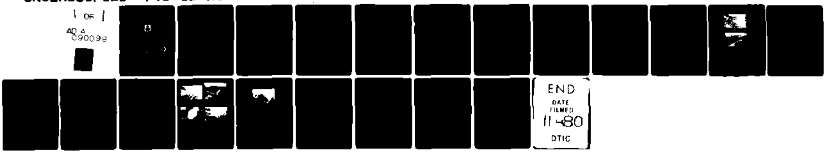

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FOREIGN TECHNOLOGY DIVISION

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by

P. Czarnocki, R. Switkiewicz

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Interleaved Structures-Cellular Filler Made of Polymer Composites

by: P. Czarnocki, R. Switkiewicz

The study presents several methods of mechanizing the process of manufacturing a cellular filler made of polymer composites based on actual research work.

The ever growing range of applications of interleaved constructions is the result of the generally known features of these structures (lightness, rigidity) and the possibility of using materials which have increasingly better properties, as, e.g., foam products or polymer composites. In interleaved structures those that are competitive for metal (mainly in relation to Al alloys and materials derived from timber) are in particular the polymer composites reinforced by fibers having great resistance (e.g., glass and carbon fibers) with binders made of epoxy or polyester resins. Essential here chiefly is the relatively small density of composites (about 1.9 g/cm^3) and the high resistance to the influence of atmospheric and chemical agents.

With regard to the filler used from among the various interleaved constructions, the structures with a cellular filler are used most often. A typical cell shape is the regular hexagon defined by the diameter of an inscribed circle. Domestic industry, chiefly by the production of communi-

[Translator's note: precure should read pre-curing] cations equipment, controlled the lot production method of this type of filler from Al foil and paper, but in the case of a cellular filler made of composites this problem remained unsolved. It is true that the method of manual formation of filler is known by using shaping cores (the cell outline represents a cross-section of the shaping core), but due to substantial difficulties in the mechanization of this process it is used only in unit production.

The new method described later of producing a cellular filler made of polymer composites (patent application No. P-209402) solves the problem of producing this type of filler under industrial production conditions (lot and large-lot). The method was worked out by the Scientific-Research Group[1] at the Institute of Aircraft Engineering and Applied Mechanics of Warsaw Polytechnic.

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[1] Scientific-Research Group of Aircraft Technology of Composite Construction. Invention authors R. Switkiewicz-adjunct-group leader, Piotr Czarnocki, M. Eng. -Chief Asst. Jerzy Kedzierski, M. Eng. -Asst. Przemyslaw Plecinski-Asst., Stanislaw Skrzypek, Eng.

Technology of a Cellular Filler Made of a Polymer Composite Manufactured by the SPU Method

The substance of the SPU method (control by hardening process) is based on the proper use of the property of the composite binder in the process of its hardening. Hardening of the polymer binder is, above all, a function of temperature and time. The chemical process of the reaction of active groups of the mixture components[2] leading to the manufacture of a stable network product can be broken up into stages adapted to the needs of the hardening process of the composite. The process given below shows how the course of the phenomenon of the hardening of a polymer binder is used in the manufacture of a filler.

Outline of Course of the Hardening Process of a Filler by the SPU Method

The hardening process runs in the following principal stages:

-- formation of flat filler pack

-- precure of the pack

-- elastic strain of the pack into a cellular structure

-- after-bake of the filler.

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[2] Set of components characterized by capability of chemical reaction leading to change of liquid state to network-like and infusible solid product.

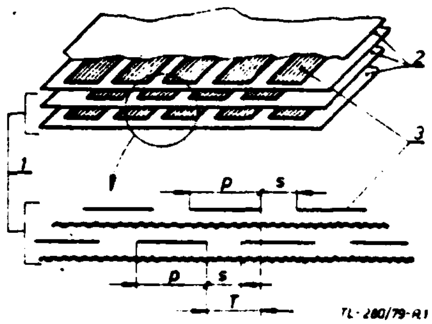

Fig. 1. Formation of flat filler pack : 1-elementary pack; 2-layers of impregnated fabric of reinforcement; 3-divider strips (foil); s-width of glue joint, p-width of divider strips, T-constant pitch of strips $T = \frac{P+s}{2}$

Formation of the flat pack depends on the successive placing of a layer of a non-hardened composite (e. g., a glass fabric impregnated by a mixture or so-called preimpregnate), a layer of divider strips (e. g., polyethylene foil), of a successive layer of the composite and a layer of divider strips moved with respect to the first layer of strips to the constant pitch T. Figure 1 presents the method of forming the flat pack.

After formation of the flat pack there takes place the precure of the binding material in the composite in order to partially disperse the binder to a degree which will ensure the glue joints the proper resistance necessary during the elastic strain of the pack into a cellular structure, while ensuring the composite layers themselves--producing the remaining cell walls--the grant of elastic properties necessary during the required strains. The precure of the flat pack depends on the realization of a specific heat cycle. The proper pressure is also necessary to achieve glue joints between the composite layers which have the resistance required.

Elastic strain of the pack into a cellular structure takes place directly after precure. This depends on stretching the pack through applying the force gathered to the external cells on both sides of the pack. The size of the stretched block should take into account the so-called spring-back of the filler block after after-bake (Fig. 2). This size depends on the weave and grams per square meter of the reinforcement (fibers) and on the type of binder in the composite. The filler in the stretched condition undergoes a thermal cycle for the purpose of after-bake of the binder in the composite. The parameters of this cycle should ensure complete network of the binder which decides the conservation of the cellular structure during neglibible spring-back.

Figure 3 shows the parameters of precure and elastic strain for the selected domestic epoxy binder, hardened at increased temperatures.

Range of Materials

Using the SPU method cellular fillers can be made from fabrics from glass fiber, carbon fiber and others (e. g., cotton), paper, and the like. The requirements of the method concerning binders are fulfilled practically by all constructional polyester and epoxy resins, and the like, since their hardening process is a function of time and temperature. The substance of the problem depends on the selection of the proper parameters (temperature, time

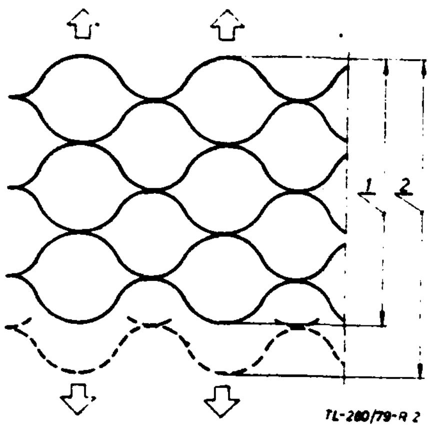

Fig. 2. Flat pack stretched into cellular structure: 1-nominal size of filler block; 2-size of stretched filler block

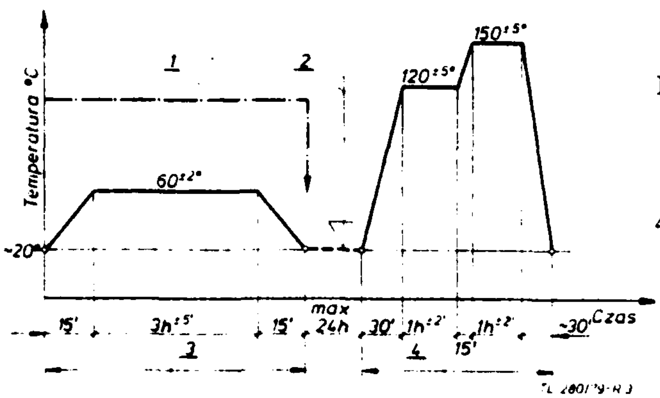

Fig. 3. Hardening parameters of Epidian 53 with CDA hardener. 1-pressures Q~ 0.2 MPa; 2-stretching of filler pack; 3-precure; 4-after-bake.

for precure and after-bake of the resin considered (binder).

During research on the elaboration of the SPU method domestic and imported glass fabrics of varied weave and grams per sq. m. underwent testing. The differences in the production process of a filler made from fabric with varied grams per sq. m. mainly give rise to differences in spring-back during stretching and after-bake. This size for a given type of fabric can be designated experimentally in a simple manner. Testing of binders was limited to domestic epoxy resins, Epidian 53+ CL and Epidian 58 + CDA. In both instances a positive result was achieved, during which the binder Epidian 58-CDA indicated a decidedly greater suitability for filler production under industrial production conditions (e.g., two times greater output of the process).

Dimensions of Cellular Filler

The dimensions of the cellular filler depend on the width of the divider strips and accepted glue joint (distance between strips in the layer). Figure 4 presents the recommended geometric relationships for cell sizes. The minimum size of cell d is tied in with the grams per sq. m. of the fabric and by the ratio of $\frac{s}{d}$ since the load capacity of the glue joints after precure must be greater than the spring force during stretching of the pack. In observing the given geometrical relationships for the cell (Fig. 4) we can probably assume that in light fabrics (80-100 g/cm^2 the minimum size of cell d is about 5 mm.

The overall dimensions of the filler block practically are not limited if a binder is used for a sufficiently long production time (e.g., for Epidian 58 + CDA filler blocks can be achieved with dimensions of about 1 × 1 x 2.5m. and larger).

Density (mass property) of Filler

Density of manufactured cellular fillers depends on the grams per sq. m. of the reinforcement fabric, cell geometry and on the participation of the

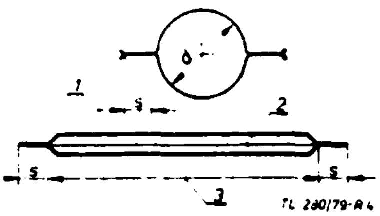

Fig. 4. Cell geometry: 1-glue joint s≈0.13d; 2-divider strip; 3-width of strip p≈1.85d; d-diameter of circle inscribed into cell.

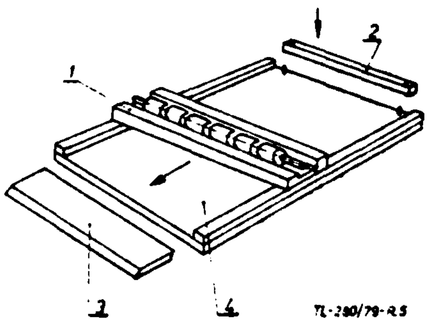

Fig. 5. Prototype instrument to form flat pack: 1-movable frame with block of spools for laying divider strips; 2-bar to fix divider strips; 3-plate for winding pack; 4-plate with guide bars.

components in the composition. The production techniques used make it possible to achieve a composite from a 70% mass participation of reinforcement (50% with impregnation). The density of the filler depending on the size of cell d and the grams per sq. m. of the reinforcement fabric g can be designated approximately by the empirical formula:

$$m = 3.6 \frac{g\,[g/m^2]}{d\,[mm]}\ [kg/m^3]$$

The cellular filler, with regard to density, is competitive in relation to the constructional foam sizes of the filler. For example, the imported foam filler Conticell used in aeronautics has a density of 40-80 kg/m^3, while a cellular filler made of glass fabric with 80 g/m^2 and cell diameter of d≈8 mm. has a density of about 36 kg/m^3.

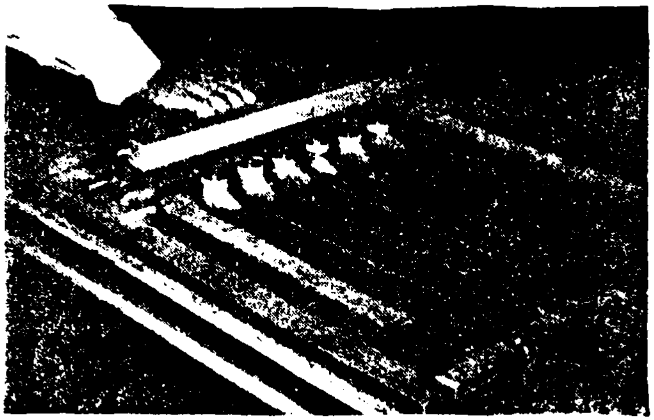

Fig. 6. Laying of first layer of strip-displacement of movable frame along guide bars.

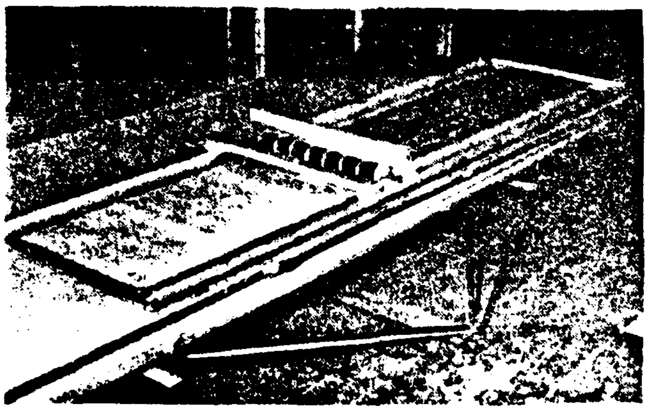

Fig. 7. Arrangement of strips-overall view.

Output of Filler Production Process

Output depends chiefly on the production technology used and the development of the binder (certain limitations result from so-called production times for an impregnated mixture). By using fabric of standard 1 m. width and Epidian 58 CDA mixture in one production cycle which runs about 11 hrs. 2.4 m^2 of cellular filler can be produced. It should be pointed out that about

50% of the time in this production cycle is taken by precure and after-bake which does not directly affect the work absorption of the product.

Production Technology of Cellular Fillers Using the SPU Method

In producing the filler two special devices are used: an attachment for forming the flat pack and an attachment for stretching the pack into a cellular structure. They enable the production of filler blocks in a cubicoid shape. In the case of manufacturing rolled blocks additional flat outline templets are used for shape cutting.

Flat Pack Formation

Flat packs can be produced by two methods. The first method is based on the formation of an elementary flat pack: composite-strips-composite-strips, in an arrangement of a strip with the larger size in the direction of the laying of separator strips. Such a formed flat pack is then wound on a flat board, achieving in this manner on both of its sides, two flat packs ready for precure. The number of complete revolutions of the board indicates the number of cells in the packs in the direction of stretching. After precure (without removal from the board) both flat packs-after cutting along the edges of the board and separating from it-undergo stretching and after-bake. Sample filler blocks were made by the described method using the elaborated SPU method. Figure 5 presents the prototype attachment used.

The board with the guide bars serves for arranging the sequential composite layers. Along the guide bars a frame with a block of spools is moved which serve to arrange the separator strips. Figures 6 and 7 show selected stages of arranging the first layer of strips in the impregnated layer. The figures presented concern the production of a filler with a cell where $d = 27$ mm. (width of arranged strips $p = 50 \pm 0.1$ mm., distance between strips or glue joint $S = 6.5 \pm 0.2$ mm.). The brushes seen on Figure 6 fulfill the role of pressure elements to achieve adhesion of the divider strips to the layer of impregnated fabric. The method of winding the elementary pack on the flat pack is shown in Figure 8.

The second way of formation is based on the completion of a flat multilayer pack composed of as many elementary packs as of cells foreseen in the block in the direction of stretching of the pack, and then on pre-curing (e.g., in an autoclave), cutting into segments, stretching, and after-bake.

For production purposes in a process having large output the following solutions to mechanized equipment is foreseen: flat formation with winding in an arrangement as in Figure 9 and continuous winding (Figure 10). Up to now preliminary tests are being conducted with a device operating in a continuous winding system (Figure 10) and satisfactory results are obtained.

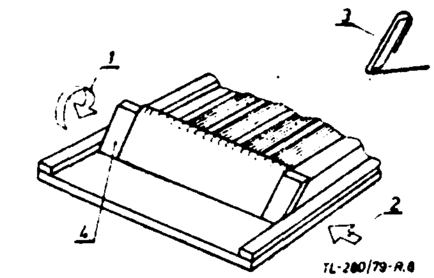

Fig. 8. Winding of elementary pack on board: 1-direction of winding; 2-direction A; 3-view from direction A; 4-board during winding based in guide bars.

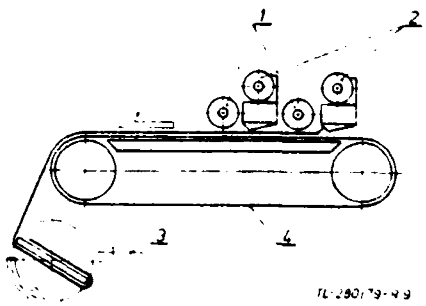

Fig. 9. Flat formation with winding in fixed arrangement: 1-divider strips; 2-fixed impregnation of fabric; 3-winding of elementary pack; 4-tape V const.

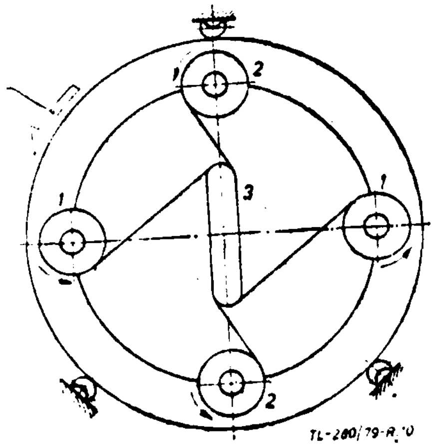

Fig. 10. Fixed winding of flat pack: 1-impregnated fabric; 2-divider strips; 3-stationary board; 4-fixed rotational speed.

Stretching of Flat Pack into Cellular Structure

The system of stretching used does not differ basically from systems used, e.g., in stretching metal fillers. Its essence is based on the use of rollers laced through the extreme cells of the pack, to which force is applied

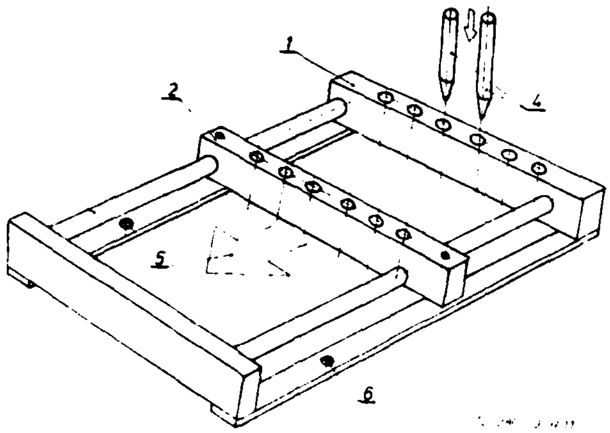

Fig. 11. Device for stretching pack into cellular structure: 1-fixed strip; 2-movable strip; 3-guide bar; 4-rollers to reinforce filler; 5-direction of stretching; 6-opening fixing movable strip.

during stretching. Thanks to the great tractability of the pack after precure a constant tread was able to be used. Figure 11 presents the overall system of the device while the sequential stages of pack stretching are shown in Figures 12-16.

After stretching the pack into a cellular structure the divider strips must be removed from the cells, e. g., by blowing the block with clean compressed air. The manual stretching process, as practice shows, is relatively simple and quick and does not require special qualifications. Also for this reason it is the opinion of the authors that mechanization of this process is not necessary (as, e. g., in the production of metal fillers).

Filler Block Profiling

Shape cutting of the filler block can be done after precure before stretching or on a finished filler after spring compressing of the filler into a

Fig. 12. Insertion of rollers into exterior pack cells.

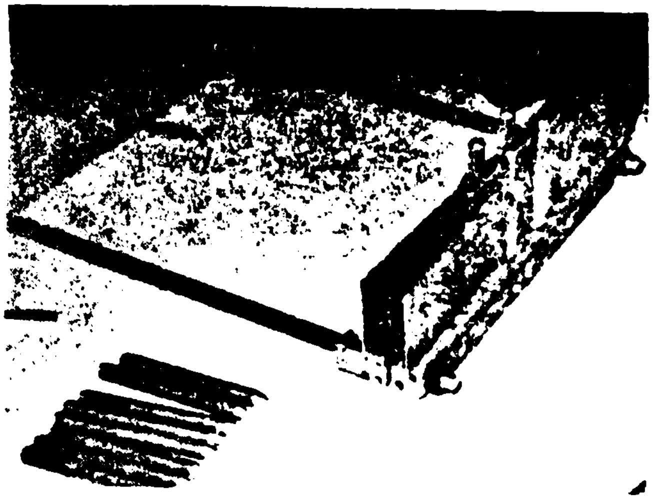

Fig. 13. Placement of pack in device.

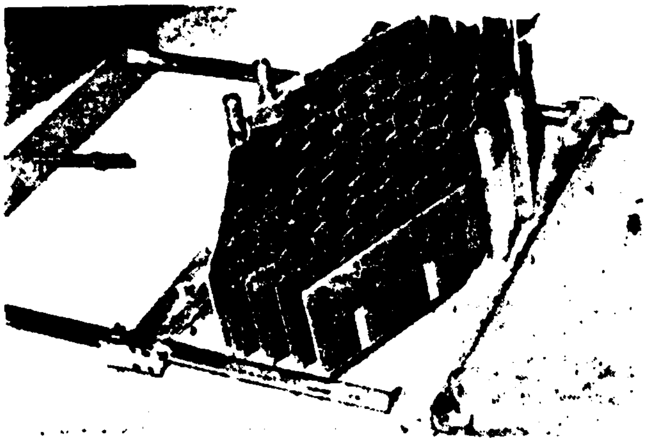

Fig. 14. Preliminary stretching of pack.

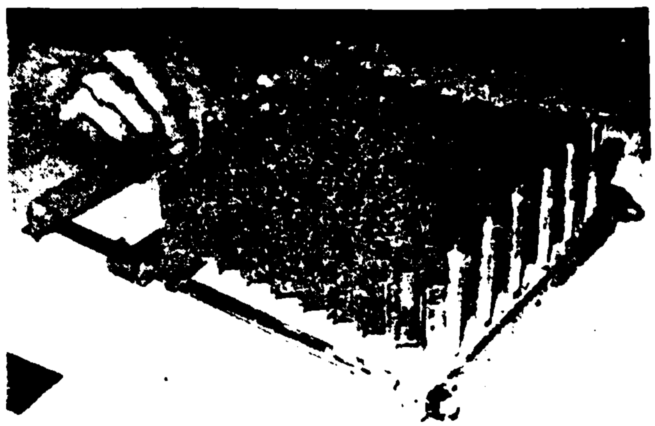

Fig. 15. Fastening of rollers

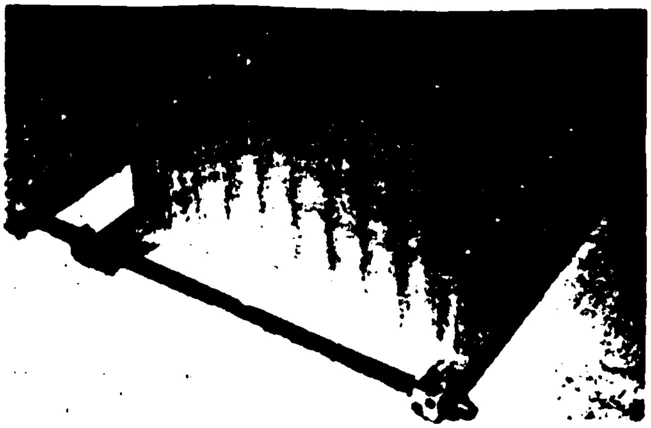

Fig. 16. Filler ready for after-bake.

flat pack. Satisfactory results of filler profiling are given by typical machines used in woodworking.

Resistance Properties of Filler Produced by SPU Method

Diagnostic tests included static resistance during compression and elastic qualities at room temperature. During static compression the range of testing was limited to a filler manufactured from a glass and epoxide composite:

-- reinforcement-glass fabric 92110 by Interglass-161 g/m.

--binder-Epidian 58+CDA.

The effect of the cell size d on the destructive stress during compression was tested. Following are the results obtained: when $d = 19$ mm, $\sigma_c = 1.01$ MN/m^2; when $d = 27$ mm, $\sigma_c = 0.57$ MN/m^2 and when $d = 36$ mm, $\sigma_c = 0.24$ MN/m^2.

A comparison of resistance during compression of a filler produced by the SPU method with another filler from a composite produced e. g., in the aeronautics industry (by manual formation method) is difficult, since it is made of fabric 130 g/m^2, has cells where $d \approx 25$ mm. and density of 20 kg/m^3, and $\sigma_c \approx 0.35\ MN/m^2$. For that reason in this case the efficiency of both these fillers can be compared.

If we assume that efficiency $\eta = \frac{\text{resistance during compression}}{\text{mass density}}$

we can prove that the efficiency of a filler made b y the SPU method is greater up to about 50% than the efficiency of a filler made by a manual formation method. The modulus of rigidity G of the filler is designated in the scope of elastic properties during shear. For a filler with a cell where $d = 27$ mm, made from a composite achieved as above: $G_1 = 37\ MN/m^2$ (G_1-modulus in the direction of filler glue joints) and $G_2 = 18\ MN/m^2$ (G_2 - modulus in the direction perpendicular to the glue joints). Testing was conducted on samples in a sample construction arrangement (the tested filler was glued on both sides by coats having great rigidity.

General Remarks

One of the most difficult problems in the production of a structure made of polymer composites is the mechanization of production processes. In the case of many structures this problem still remains unresolved. Manual production of composites is one of the chief reasons of their limited use in structures where the features of these materials could be fully used. The chief difficulties in the mechanization of production processes of products made from composites are:

- complexity and great demands of the technological processes of constant impregnation of reinforcement (fabric, rowing),

- long hardening time of the majority of currently accessible polymer binders and short ~~production~~ time of their utilization (the long production cycle of the product, moreover is a consequence of a long hardening time).

- specifics of production of structures made of composites as the result of using the principle of constant shaping of the product, i. e., limitations to a minimum number of joints of construction elements which were hardened earlier.

Partial solution of the problems discussed can be attained, e. g., by using impregnates. The production process gives rise to the formation of a structure and composite hardening; on the other hand, problems connected with the impregnation of the reinforcement fall away. Domestic industry has not solved this very serious problem up to now and consequently is still lacking a foundation for broader mechanization of manufacturing processes of products made from composites.

The technology presented of SPU production of a cellular filler is a test of surmounting the difficulties discussed in the mechanization of the process of its production. The goal was reached using certain special properties of the composite binder in the process of its hardening. This line of approach to the technology of products made of polymer composites conceals within itself many other different unknown solutions and makes it possible to hope for a new technology suitable for mechanization. Certain problems from this field concerning the production of unfolded interleaved casings (wing torque boxes, concave swedges), are the subject of research conducted by the Group.

Notes on the Production Process of the Cellular Filler Using the SPU Method

- The filler can be made practically from any accessible domestic glass fabrics (unfortunately a limited assortment) with the use of domestic constructional epoxy and polyester resins.

-Cell sizes are limited only by a minimum size of $d \sim 5$ mm.

- Density of the filler can be adjusted to the needs controlling the size of the cell and the grams per sq. m. of the reinforcement.

- Overall dimensions of the filler block and the output of the process can be adjusted to needs by using the proper instrumentation and composite materials.

- The simple production technology enables production even with modest equipment and the use of full mechanization (with the exception of pack stretching).