

SPECIFICATION

Method of densifying open-celled polyurethane material

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Background of the invention

Field of the invention

This invention relates to a method of densifying a mass of open-celled polyurethane foam, either polyether or polyester. While the method is advantageous for material of any thickness, it is especially valuable in treating material which is several inches thick.

Previous methods of densifying open-celled plastic foam articles have relied on the extended application of heat and substantial compressive forces to the surface of the article. This is often carried out by means of large heated metal molds or platens between which the foam is placed. Heat is transmitted to the foam by conduction from the heated platens for a substantial period of time. The low K-factor of air and of polyurethane makes such heating processes very time-consuming.

A commercially acceptable polyurethane foam requires a density and other physical characteristics which are quite uniform throughout. This can only be achieved by bringing all parts of a mass of such foam into a predetermined temperature range during processing because the material will return to its pre-treatment state if the treatment temperature is too low, and this necessarily causes a non-uniform product if some parts of the mass are sufficiently hot during treatment and others are not. Prior art processes inherently tend to produce non-uniform material, and are difficult to control because of the very low K-factors previously mentioned.

U. S. Patent No. 3,577,519 (Gambardella) describes a method of densifying polyurethane foam buns wherein partially cured foam is compressed while still at or near its exothermal reaction temperature. This process may result in non-uniform temperatures and uncontrollable densification, at least in part, due to the relatively rapid cooling of the exterior of the mass and the typically large size of polyurethane reaction buns. This problem is only partially alleviated by the use of heat compression means. Also, the process may not be used to densify fully cured foam.

Further, the heating of a mass of foam by conduction, as in the above-described prior processes, is very inefficient, as great amounts of heat are required to initially heat the compression means, which are often massive, and then to maintain the temperature of the compression means while they are in prolonged contact with the foam.

Another source of inefficiency in previous compression methods is the inability of those methods to adapt to continuous operating conditions. The nature of the prior processes eliminates anything but extremely thin material for densification on a continuous system. Prior processes were generally operated on an intermittent basis which would result in platen marks on continuous strips of foam greater than about 3/32" thick.

Another disadvantage associated with prior compression densification methods as applied to cured polyurethane is that very high compressive forces are required until the mass reaches the proper temperature. This requires the use of massive compression equipment, the cost of which further detracts from the desirability of prior compression methods.

U. S. Patent No. 3,475,525 (Peters) describes a method of reticulating open-celled polyurethane foam whereby a stream of heated gas is passed through the foam in order to heat the foam so as to melt or thermally decompose membranous cell walls without melting the network strands supporting the cell walls. The gas temperature must be above 250°C. and is generally between 400°C. and 800°C., and the thickness of the foam must be less than 0.75 inches to prevent degradation of the network structure. Additionally, the gas velocity through the foam must be in excess of one meter per second.

The method of the present invention preserves the cell integrity, since gas temperature and velocity are substantially less than in Peters. Further, the present invention may be effectively applied to foams of thickness much greater than 0.75 inches, the upper limit of the Peters method.

Summary of the invention

It is an object of the invention to provide an improved method of densifying a mass of cured open-celled polyurethane foam.

It is a further object of the invention to provide a method of densifying open-celled polyurethane foam which may be carried out so as to provide an end product of uniform density throughout.

Another object of the invention is to provide a method of densifying fully cured open-celled polyurethane foam wherein small compressive forces are required to effect densification.

It is a further object of the invention to provide a method of rapidly densifying open-celled polyurethane foam which may be carried out on continuous rolls as well as on separate slabs.

Yet another object of the invention is to provide a method of using circulating hot air to rapidly raise the foam into the proper temperature range while so controlling temperature and air velocity so as to avoid breaking down the membranous and skeletal structure of the material.

According to the present invention there is provided a method of densifying a mass of cured open-celled polyurethane foam, said method comprising the consecutive steps of passing heated gaseous material through the mass, the temperature of said gaseous material being in the range of about 385°F to 450°F and the velocity of said gaseous material being insufficient to destroy the integrity of the cell walls of the mass, said gaseous material being inert with respect to the polyurethane, and the period of exposure of the mass to the gaseous material being insufficient to allow charring of the mass, yet sufficient to raise the entire mass substantially uniformly to a temperature between about 385°F and 450°F, compressing the mass while

its temperature is between about 385°F and 450°F to reduce its thickness and thus increase its density to a desired degree; and permitting the mass to cool.

The invention also includes a method of
 5 densifying a mass of cured open-celled polyurethane foam, said method comprising the consecutive steps of passing heated gaseous material through the mass, the temperature of said
 10 gaseous material being in the range of about 425°F to 450°F, and the velocity of said gaseous material being insufficient to destroy the integrity of the cell walls of the mass, said gaseous material being inert with respect to the polyurethane, and the period of exposure of the mass to the gaseous material being
 15 insufficient to allow charring of the mass, yet sufficient to raise the entire mass substantially uniformly to a temperature between about 425°F and 450°F, compressing the mass while its temperature is between about 425°F and 450°F to reduce its
 20 thickness and thus increase its density to a desired degree; and permitting the mass to cool.

If desired the period of exposure of the mass to the gaseous material may be sufficient to raise the temperature of the mass to a temperature between
 25 about 425°F and 435°F compression being carried out while the temperature of the mass is between 425°F and 435°F. Preferably the gaseous material is air, which may be circulated downwardly through the mass while the mass is maintained in the
 30 temperature range of 385°F to 450°F or in the preferred temperature range of 425°F to 450°F for a time not exceeding about 1 minute. The mass may be moved into a zone at ambient temperature immediately after it is compressed and in one
 35 method in accordance with a feature of the invention the mass is moved continuously endwise and is compressed between pinch rollers, the mass being permitted to cool by moving the mass endwise out of the pinch rollers into a zone at ambient
 40 temperature. In accordance with another method the mass may be moved in a discontinuous fashion so that compression may be effected between two flat parallel surfaces at least one of which comprises a movable platen.

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The drawings

Figure 1 is a longitudinal central sectional view of an apparatus for practicing the method of the invention; and

50 *Figure 2* is a transverse sectional view taken substantially as indicated along line 2-2 of *Figure 1*.

Detailed description of the invention

Figure 1 illustrates an apparatus, generally
 55 designated 10, to permanently compress and thereby densify a mass 12 of open-celled polyurethane foam. The foam used is fully cured. The apparatus 10 comprises a base (not shown) which includes a planar horizontal support (not shown), an upstanding support means (not shown),
 60 an endless conveyor means 14, gas heating and circulating means 16, and compressing means 18 which form an integral part of the heating and circulating means 16.

65 The purpose of the invention is to densify the

mass 12 of open-celled polyurethane foam, which is preferably and illustratively a continuous strip 20, but which may be in the form of separate slabs for batch treatment. The mass 12 may be 4" or more in
 70 thickness and have a density as low as about 0.9 lb/ft³. The density of the mass 12 will generally be between 1.3 lb/ft³ and 2.0 lb/ft³.

The conveyor 14 comprises an endless open mesh belt 22 which travels about a drive drum 24 and a pair of idler drums 26 which carry the belt 22 in the direction of the arrow 27 through a horizontal working run 28 and a return run 30.

One portion 32 of the horizontal working run 28 traverses and is effectively enclosed by a chamber 80 34 of the gas heating and circulating means 16, said chamber 34 comprising an upper portion 36 and a lower portion 38 disposed above and below the horizontal working run 28, respectively.

Referring to *Figure 2*, the gas heating and
 85 circulating means 16 comprises an endless conduit system including both portions of said chamber 34 and a housing 40 containing a blower 42 and heating means 44. The upper portion 36 of the chamber 34 is defined by said portion 32 of the horizontal working run 28, part of an upper wall 46, an inner wall 48, an outer wall 50, and parts of a front wall 52 and a rear wall 54, seen in *Figure 1*.

The endless conduit system has a hood-like upper member which includes the upper portion 36 of the chamber 34, an upper section 56 of the housing 40, and a trough-like lower member 37 which provides the lower portion 38 of the chamber 34 and constitutes the gas inlet for the blower 42.

The trough-like lower member 37 is defined by
 100 said portion 32 of the horizontal run 28, an inner wall 58, an outer wall 60 and an arcuate side and bottom wall 62 (*Figure 1*). The lower section of the housing 40 is formed by a section of an inner wall 66, an outer wall, 68, a transverse wall 70 extending between the walls 66 and 68, and a transverse wall (not shown) which is parallel to the wall 70.

The blower 42 is a conventional type powered by a motor 64. In operation, the blower 42 circulates gas in the direction of the arrows shown in *Figure 2*. The
 110 heating means 44 is located above, and thus downstream of, the blower 42 and illustratively comprises a plurality of electric heating elements 72. The upper section 56 of the housing 40 is defined by the upper margin of the heating means 44, the upper part of the inner wall 66, an outer wall 74, part of the upper wall 46, and those parts of the front and rear walls 52 and 54 which extend transversely between the walls 66 and 68.

Referring to *Figure 1*, it is to be noted that the horizontal run 28 of the conveyor 14 and the foam mass 12 carried thereon enters the chamber 34 through an elongate slot 76 and that the bottom of the horizontal run 28 contacts a pair of upstanding sealing walls 78, seen in *Figure 2*. The vertical
 120 dimension of the opening 76 corresponds closely to the vertical dimension of the combination of the horizontal run 28 and the mass 12, thereby effecting a seal about the mass 12 and the working run 28, and external upper and lower lipped flanges 80 and 81,
 130 respectively, aid in reducing the escape of the

circulating gas. It is to be understood, however, that the seal is intended only to contain most of the circulating gas and not to provide absolute containment.

- 5 The compression means 18 adjoins the gas heating and circulating means 16 at the rear wall 54 thereof, and encloses a section 82 of the working run 28. As seen in Figure 1, the compression means 18 comprises a housing 84, including a top wall 86, a bottom wall 88, upper and lower rear walls 90 and 92, respectively, a rear upstanding wall 94 connected to the wall 62, a side wall 96 extending between the rear walls 90 and 92 and the wall 94, and a second side wall (not shown) disposed opposite the side wall 96. The housing 84 communicates with the chamber 34 through an opening 97 in the wall 54. A deflector plate 98 extends between the walls 48 and 50 of the heating chamber 34 to direct heated gas into the opening 97.
- 20 The housing 84 contains compressing means 99, illustratively comprising a plurality of driven steel pinch rollers 100. It may be understood that other compressing means, such as platens, may be used. Platens are suitable for batchwise compression of foam slabs.

The section 82 of the working run 28 travels over a roller 102 then under a roller 104 disposed below the rollers 100, and then over a roller 106 at the downstream end of the housing 84, whereby the working run 28 is separated from the strip 20 of polyurethane foam so as to facilitate the simultaneous application of pressure to both sides of said strip.

- The rollers 100 may be coated with a release agent which facilitates separation of the strip 20 from the rollers 100 after compression of the foam. The rollers 100 should be maintained at or very near the temperature of the circulating gas and the strip 20 in order to prevent premature cooling of the surface of the strip 20, which would result in non-uniform densification. Deflection of heated gas from the chamber 34 into the housing 84 by the deflection plate 98 helps maintain the temperature of the rollers 100 and the strip 20 at a sufficiently uniform, high level to result in uniform densification.

The strip 20 and the working run 28 exit the housing 84, preferably into a zone at ambient temperature, through a shallow elongate opening 108 between the walls 90 and 92. While the vertical dimension of the opening 108 is not so small as to form an absolute seal about the strip 20 and the working run 28, it is sufficiently small to prevent the loss of any substantial amount of heated gas. The slot 76 and the shallow opening 108 allow moderate escape of heated gas from the system, and the entry of make-up gas.

- In operation, the mass 12 is placed on the conveyor 14 and is carried into the chamber 34 where it is contacted by the circulating heated gas.
- 60 The gas is commonly and illustratively air, but may be another gas or mixture of gases in certain situations. The circulating gas must be chemically inert with respect to the polyurethane, but not otherwise have a tendency to impart undesirable characteristics to the foam.

The circulating air is heated to a temperature between about 385°F and 450°F or preferably between about 425°F and 450°F, by the heating means 44, and is directed into the chamber 34 where it is drawn downwardly through the mass 12 and the working run 28 by the suction produced by the blower 42, which creates a lower pressure in the lower portion 38 than in the upper portion 36 of the chamber 34.

- 75 The open-celled structure of the foam allows the heated air to intimately contact the entire interior cell structure of the foam, thereby rapidly heating the mass 12 to a temperature which is substantially uniform throughout the mass and which is identical to or very near the temperature of the circulating air, i.e., between about 385°F and 450°F or preferably between about 425°F and 450°F. Alternatively the mass may be heated only to a temperature between 425°F and 435°F. It is important that the mass 12 does not reach a temperature above approximately 475°F. (about 245°C.), as undesirable charring of polyurethane begins at about that temperature.

After the temperature of the mass 12 is raised to a temperature between 385°F and 450°F, the mass 12 exits the chamber 34 and enters the housing 84 via the opening 97, and is fed between the steel pinch rollers 100, while separated from the working run 28.

- The internal resistance of the mass 12 to compressive force is greatly reduced when the temperature of the mass is between about 385°F and 450°F. In that temperature range, the state of the mass approximates that of its exothermal reaction stage, during which it has low resistance to compressive force and little resilience. As a result, a permanently densified strip 20a may be produced by the application of a relatively small compressive force for a comparatively short time relative to those necessary with previous compression methods. The pressure may be less than 10% of that required by previous methods; and after a brief period of compression, the compressive force may be removed at once without fear of subsequent expansion.

- Cooling of the mass to below 385°F. immediately after compression insures permanence of the densification. Cooling occurs very rapidly because of the low specific heat and relatively low density of the mass even after densification. This allows higher production rates than were possible with older methods of densification. Also, the need for heavy molds or platens is obviated, thereby allowing for decreased capital cost. The relative vertical spacing of the rollers 100 is adjustable, thereby allowing for different desired final thicknesses and, therefore, different final densities of the densified strip 20a. The final density of the strip 20a may be up to about 30 lb/ft³.

- As an alternative to pinch rollers, two movable platens, or one movable platen and a stationary surface, may be employed as the compressive means 99. If so employed, a first platen is disposed above the mass 12 with its horizontal surface substantially parallel to the upper surface of the mass, and a second platen (or stationary surface) is disposed below the mass 12, with its surface

substantially parallel to the surface of the first platen. The upper platen, or both platens, are moved vertically toward one another so as to apply compressive forces to the upper and lower surfaces of the mass.

It may be noted that certain aspects of the operation are different if platens are used as the compressing means, rather than pinch rollers. Operations with platens are necessarily performed in a discontinuous manner, as it is necessary to stop the movement of the conveyor when the platens are in their closed position around the mass 12. The use of platens is especially suitable for use with individual slabs of foam as opposed to continuous strips, although platens may be used to successively densify portions of a strip, thereby effecting densification of the entire strip.

The surfaces of the compressing means 99 may be smooth or embossed, depending on the desired surface appearance of the finished product.

After compression, the densified strip 20a and the working run 28 exit the housing 84 through the opening 108; and after the strip 20a has cooled, it may be further cut, shaped, etc.

It may be noted that the cooling process is extremely rapid, due to the low specific heat and low apparent density of the polyurethane mass 12. Further operations may be undertaken almost immediately after the strip 20 exits the housing 84.

It is to be understood that the use of the subject invention is limited to those polyurethane foams which have an open-celled structure which allows penetration of the foam by the flow of heated gaseous material. It should also be noted that either open-celled polyester or polyether urethane may be employed with equally good results.

In this specification we should add that the Fahrenheit temperatures quoted have the following values in the Centigrade scale:-

425°F = 218°C

450°F = 232°C

435°F = 224°C

475°F = 246°C

385°F = 195°C

CLAIMS

1. A method of densifying a mass of cured open-celled polyurethane foam, said method comprising the consecutive steps of passing heated gaseous material through the mass, the temperature of said gaseous material being in the range of about 385°F to 450°F, and the velocity of said gaseous material being insufficient to destroy the integrity of the cell walls of the mass, said gaseous material being inert with respect to the polyurethane, and the period of exposure of the mass to the gaseous material being insufficient to allow charring of the mass, yet sufficient to raise the entire mass substantially uniformly to a temperature between about 385°F and 450°F, compressing the mass while its temperature is between about 385°F and 450°F to reduce its thickness and thus increase its density to a

desired degree; and permitting the mass to cool.

2. A method of densifying a mass of cured open-celled polyurethane foam, said method comprising the consecutive steps of passing heated gaseous material through the mass, the temperature of said gaseous material being in the range of about 425°F to 450°F, and the velocity of said gaseous material being insufficient to destroy the integrity of the cell walls of the mass, said gaseous material being inert with respect to the polyurethane, and the period of exposure of the mass to the gaseous material being insufficient to allow charring of the mass, yet sufficient to raise the entire mass substantially uniformly to a temperature between about 425°F and 450°F, compressing the mass while its temperature is between about 425°F and 450°F to reduce its thickness and thus increase its density to a desired degree; and permitting the mass to cool.

3. A method of densifying a mass of fully cured open-celled polyurethane foam, said method comprising the consecutive steps of passing heated gaseous material entirely through the mass, the temperature of said gaseous material being in the range of about 425°F to 450°F and the velocity of said gaseous material being insufficient to destroy the integrity of the cell walls of the mass, said gaseous material being inert with respect to the polyurethane, and the period of exposure of the mass to the gaseous material being insufficient to allow charring of the mass, yet sufficient to raise the entire mass substantially uniformly to a temperature between about 425°F and 435°F; compressing the mass while its temperature is between about 425°F and 435°F to reduce its thickness and thus increase its density to a desired degree; and permitting the mass to cool.

4. A method according to claims 1 or 2 or 3 wherein the gaseous material is air.

5. A method according to any of the preceding claims wherein the gaseous material is circulated downwardly through the mass.

6. The method according to any of the preceding claims wherein the mass is maintained in the temperature range of 385°F to 450°F for a time not exceeding about one minute.

7. A method according to any of claims 1 to 5 wherein the mass is maintained in the temperature range of 425°F to 450°F for a time not exceeding about one minute.

8. A method according to any of the preceding claims wherein the mass is moved into a zone at ambient temperature immediately after it is compressed.

9. A method according to any of the preceding claims wherein the mass is moved continuously endwise and is compressed between pinch rollers.

10. A method according to any of the preceding claims wherein the mass is permitted to cool by moving it endwise out of the pinch rollers into a zone at ambient temperature.

11. A method according to any of the preceding claims 1 to 8 wherein the mass is moved in a discontinuous fashion and is compressed between two flat parallel surfaces.

12. A method according to claim 11 wherein at



substantially parallel to the surface of the first platen. The upper platen, or both platens, are moved vertically toward one another so as to apply compressive forces to the upper and lower surfaces of the mass.

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desired degree; and permitting the mass to cool.

2. A method of densifying a mass of cured open-celled polyurethane foam, said method comprising the consecutive steps of passing heated gaseous material through the mass, the temperature of said gaseous material being in the range of about 425°F to 450°F, and the velocity of said gaseous material being insufficient to destroy the integrity of the cell walls of the mass, said gaseous material being inert with respect to the polyurethane, and the period of exposure of the mass to the gaseous material being insufficient to allow charring of the mass, yet sufficient to raise the entire mass substantially uniformly to a temperature between about 425°F and 450°F, compressing the mass while its temperature is between about 425°F and 450°F to reduce its thickness and thus increase its density to a desired degree; and permitting the mass to cool.

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7. A method according to any of claims 1 to 5 wherein the mass is maintained in the temperature range of 425°F to 450°F for a time not exceeding about one minute.

8. A method according to any of the preceding claims wherein the mass is moved into a zone at ambient temperature immediately after it is compressed.

9. A method according to any of the preceding claims wherein the mass is moved continuously endwise and is compressed between pinch rollers.

10. A method according to any of the preceding claims wherein the mass is permitted to cool by moving it endwise out of the pinch rollers into a zone at ambient temperature.

11. A method according to any of the preceding claims 1 to 8 wherein the mass is moved in a discontinuous fashion and is compressed between two flat parallel surfaces.

12. A method according to claim 11 wherein at



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least one of the flat parallel surfaces comprises a movable platen.

13. A method according to claim 1 or 2 or 3 of densifying a mass of cured open-celled polyurethane foam substantially as hereinbefore described with reference to the accompanying drawings.

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