United States Patent [19]

Lawson et al.

[11] **3,782,466**

[45] **Jan. 1, 1974**

[54] **BONDING CASING WITH SYNTACTIC EPOXY RESIN**

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[73] Assignee: **Shell Oil Company,** Houston, Tex.

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[52] **U.S. Cl.** **166/254,** 166/295

[51] **Int. Cl.** **E21b 33/14**

[58] **Field of Search** 166/295, 294, 292, 166/254

[56] **References Cited**

UNITED STATES PATENTS

3,722,591	3/1973	Maxson	166/295
3,456,735	7/1969	McDougall et al.	166/295 UX
3,637,019	1/1972	Lee	166/295
3,379,253	4/1968	Chism	166/295

Primary Examiner—Stephen J. Novosad

Attorney—Harold L. Denkler et al.

[57] **ABSTRACT**

In a well in which a movement of earth formation material is apt to collapse a casing, an improved bond between the casing and the sur-rounding earth formations is formed by a syntactic epoxy resin foam that collapses progressively and has a compressive strength slightly less than that of the casing.

2 Claims, 8 Drawing Figures

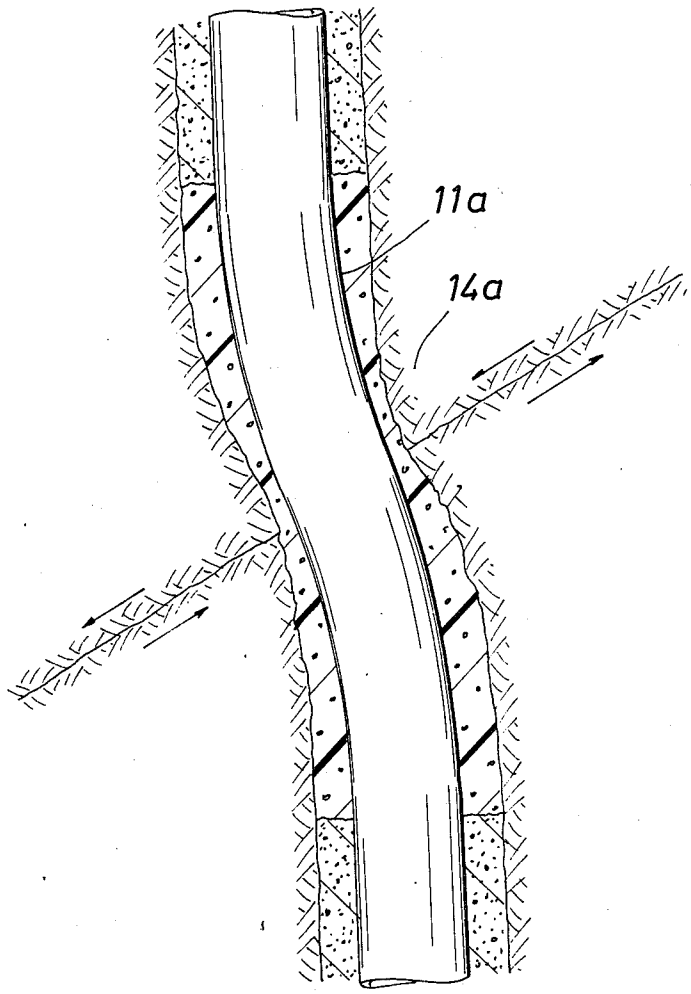
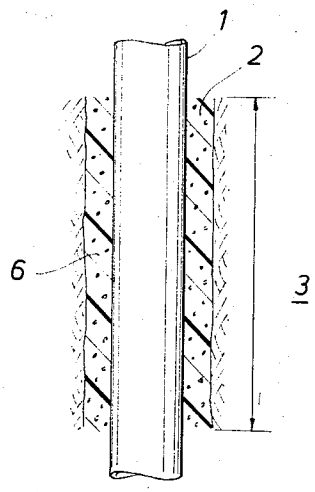
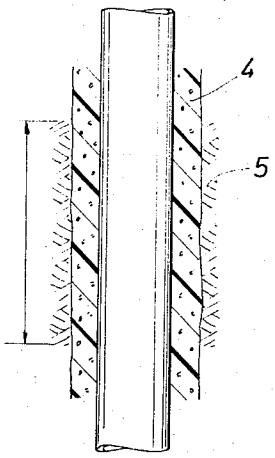


FIG. 1A



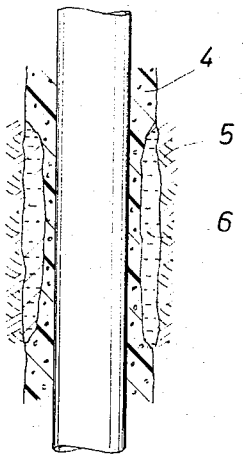
INITIAL FROZEN STATE

FIG. 1B



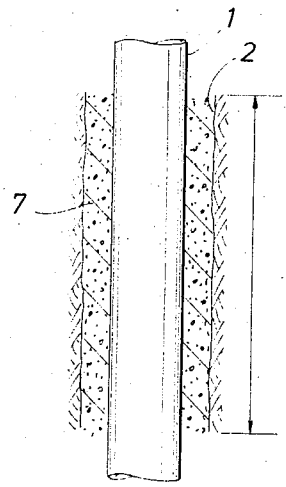
THAWED AND COLLAPSED

FIG. 1C



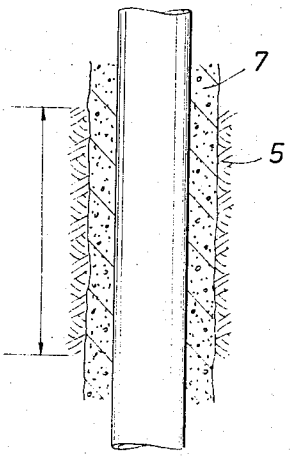
REFROZEN

FIG. 2A



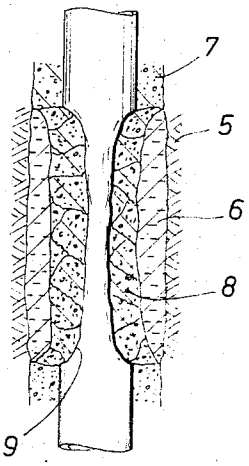
PRIOR ART

FIG. 2B



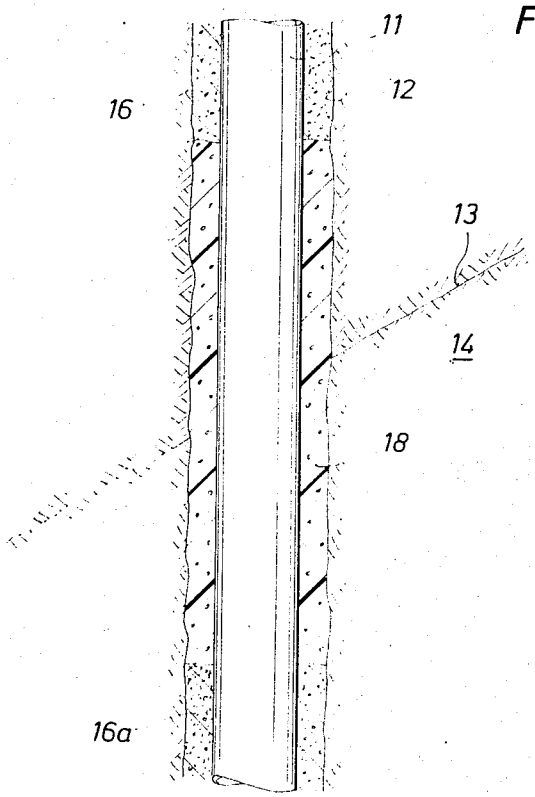
PRIOR ART

FIG. 2C



PRIOR ART

FIG. 3A



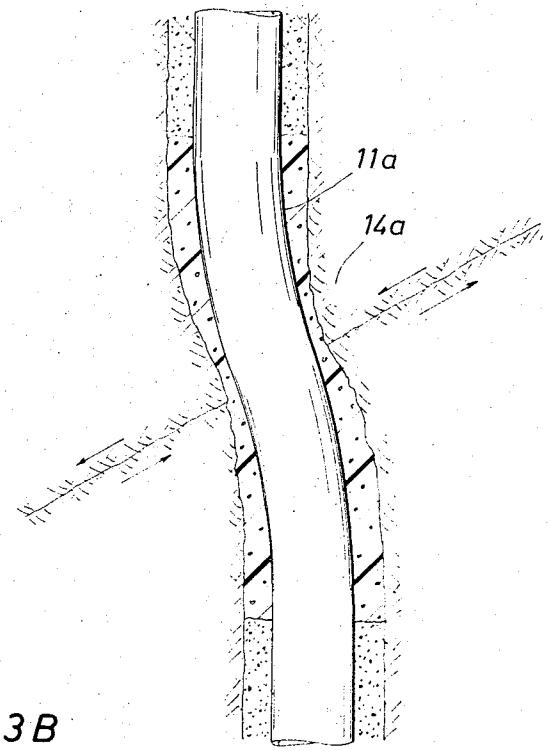


FIG. 3B

BONDING CASING WITH SYNTACTIC EPOXY RESIN

BACKGROUND OF THE INVENTION

This invention relates to casing the borehole of a well. More particularly, it relates to bonding a well casing to the surrounding earth formations at a depth at which the casing is apt to be collapsed by a movement of earth formation material toward the interior of the borehole, for example, in a permafrost zone or in a zone of fault crossing, or the like.

Well casings comprise pipe strings that are relatively long, large and expensive. In completing a well, a casing program is designed to line the borehole with a casing having at each depth a strength that is adequate but not excessive. The well casing is conventionally bonded to the adjacent earth formations by pumping a slurry of cement into the space between the casing and the earth formation ad allowing the cement to harden. In many situations, it is important that the casing to earth formation bond be both mechanically strong, to cause stresses applied to the casing to be transmitted to the earth formation, and fluid-tight, to prevent any flow of fluid between the casing and the earth formation. The conventional well cements form bonds that are mechanically strong and fluid tight, but also relatively rigid and brittle. If earth formations move toward the interior of the borehole, the cement tends to be cracked and pushed into deformations in the casing. A cracking of the cement may be caused by a slight movement of earth formation material toward the borehole interior and a casing collapse may be caused by any additional movement.

The present invention is, at least in part, premised on a discovery that (1) a mechanically strong syntactic epoxy resin foam formulation can be cured in the space between a well casing and the surrounding earth formation to form a solid resinous foam that collapses progressively and has a compressive strength that is near but slightly less than that of the adjacent section of casing and (2) such a syntactic resin-foam casing-bonding procedure provides results that are unobviously advantageous. In a permafrost zone, the endurance of a fluid-tight and mechanically strong bond between a fully open section of casing and adjacent earth formations is extended, by the cooperation between the progressive crushing, resiliency and thermal insulating properties of a syntactic epoxy resin foam. In a fault zone the endurance of such a bond is extended by the progressive crushing and resiliency properties of such a foam. A syntactic epoxy resin foam is one in which gas bubbles are dispersed in an epoxy resin and at least some of the bubbles are gas-filled, or hollow, microspheres, or micro-bubbles, such as socium silicate or high strength glass micro-bubbles.

SUMMARY OF THE INVENTION

The invention relates to an improved process for casing a well. A casing string having a strength that is adequate, but not excessive for each depth location within the well, is suspended within the borehole. At at least one depth of possible casing crushing due to a movement of earth formation material toward the interior of the borehole, a self-curing liquid syntactic epoxy resin foam formulation is flowed into the space between the casing and the earth formation. The resin formulation is adjusted to the extent required to produce a resin

having a compressive strength slightly less than that of the adjacent portion of casing. The resin formulation is cured in situ to form a syntactic epoxy resin foam. At least one other portion of the string, in a different location within the well borehole is, preferably, bonded to the adjacent earth formations by a conventional grouting material such as cement.

DESCRIPTION OF THE DRAWINGS

FIGS. 1A to 1C are schematic partially cross-sectional illustrations of a portion of well casing bonded to an earth formation in accordance with this invention.

FIGS. 2A to 2C are similar illustrations of an analagous structure in which the bonding material is cement.

FIGS. 3A and 3B are similar illustrations of a portion of well casing bonded in accordance with the present invention in a zone of fault crossing.

DESCRIPTION OF THE INVENTION

The invention can be practiced by employing known materials and techniques. Known casing program and casing string design techniques can be used to fabricate the casings to be bonded. Known well logging, or the like techniques, can be used to determine possible casing-crushing depths at which material in the earth formations encountered by the well is apt to move toward the interior of the borehole. Known compositions and techniques can be used to formulate, emplace and cure a liquid syntactic epoxy resin foam formulation that forms a resin having a compressive strength slightly less than that of the adjacent portion of casing. Suitable compositions and techniques for forming and curing syntactic epoxy resin foams are described in publications such as the American Chemical Society Epoxy Resins Advance in Chemistry Series 92, (from Symposium 155, of the ACS Meeting, 1968) the textbooks "Plastic Foams" by Calvin J. Benning, Wiley Inter Science Division of John Wiley and Sons, 1969, and the like.

The present utilization of a syntactic epoxy resin foam in a well is distinctly different from prior uses in well of syntactic or other types of resin foams. For example, U.S. Pat. No. 3,379,253 describes the plugging of a zone of lost circulation within an earth formation around a borehole by effecting an in situ foaming and curing of a polystyrene, polyurethane, or the like, resin foam within the borehole and the zone of lost circulation. The compression strength of such a foamed resin is not adjusted relative to that of the well casing, since the resin is used only to plug the pores of the earth formation. U.S. Pat. No. 3,456,735 describes a use of a foamed resin as a thermal insulating material installed in the annular space between a production tubing string and the next larger casing string. The compressive strength of the foamed resin is not adjusted relative to that of the well casing, since the resin is placed inside of the casing and is used only as an insulation.

In the drawing, FIGS. 1A to 1C show a casing 1 in a borehole 2 within an earth formation 3 in a permafrost zone. The casing to earth formation bond is formed by a syntactic epoxy resin bonding material 4 having a compressive strength slightly less than that of the adjacent portion of casing. FIGS. 1A and 1B show the tendency for the earth formation to subside and cause a redistribution into a disturbed earth formation material 5, around the casing string and bonding material. FIG.

1C illustrates the movement of earth formation material 6 that is caused by a refreezing of the permafrost. Such material may comprise ice or other frozen materials and/or rock particles of debris and portions of it are apt to move toward the interior of the borehole. Some or all of the mechanical strength and fluid permeability of the casing to earth formation bond is retained by the ability of the resin bonding material 4 to collapse progressively while resiliently pressing against the portions of earth formation material 6 that have moved into the borehole. The compressive strength of a resin foam bonding material such as material 4 is preferably from about 75 to 95 percent of the casing compressive strength of the adjacent portion of casing.

FIGS. 2A to 2C show an analagous situation in which the casing bonding material is a conventional sheath of cement 7. In this case, in the refrozen stage shown in FIG. 2C, the incursion of earth formation material 6 tends to form fractures 8 within the cement sheath 7 and to collapse the casing wall by pushing cement fragments inward to form the indentations 9 in the casing.

FIG. 3A shows a casing 11 in a borehole 12 in the zone of the crossing of a fault 13 in earth formation 14. Above and below the fault crossing zone, the casing is bonded to the adjacent portions of the earth formation with a conventional cement bonding material 16 and 16*a*. Within the fault-crossing zone, the casing is bonded to the adjacent earth formation with a strength-tailored syntactic epoxy resin foam bonding material 18, such as that described in connection with FIGS. 1A to 1C. As shown in FIG. 3B, such an earth formation fault is susceptible to shifting in a manner that forms an S curve, such as curve 11*a*, in the well casing while moving encroaching portions, such as portion 14*a*, of the adjacent earth formation towards a portion of the interior of the borehole.

As indicated in FIGS. 1C and 3B, where the casing to earth formation bonding material is a progressively compressible syntactic epoxy resin foam having a compressive strength slightly less than that of the adjoining well casing, movements of earth formation material toward the interior of the borehole tend to compress the bonding material without disrupting the fluid-tight integrity of that material or diminishing the size of the passageway within the well casing.

In completing a well that extends through a permafrost zone, in a preferred embodiment of the present invention, the well casing program is designed to include a multiplicity of casing strings, such as a conductor pipe, a permafrost string, a surface casing string, and an intermediate production string, etc. In bonding the outermost casing strings to the earth formations, each portion that is bonded to an earth formation within the permafrost zone, (i.e., in a zone of possible casing collapse) is bonded by means of a syntactic epoxy resin foam of tailored compressive strength. For example, in installing a conductor pipe having a compressive strength, such as 1,000 psi, the pipe is suspended within the borehole while a liquid syntactic epoxy resin foam formulation is pumped into the space between the pipe and the earth formation. Such a resin formulation may comprise a slurry of microspheres (available from Emerson and Curning, Inc., amount to about 60 percent by volume of the slurry in liquid comprising a mixture of about 1 part by volume Epon 828 (Shell Chemical Company) per 1 part by volume Versamide (General Mills) and 0.1 percent by weight of a blowing agent such as ammonium carbonate. Such a resin formulation reacts in situ to form a syntactic epoxy resin diafoam (one containing macro cells, formed in situ by the blowing agent, in addition to the hollow microspheres) having a compressive strength of about 500 to 1,000 psi. Each smaller casing string that has a portion exposed to earth formations within the permafrost zone is preferably also bonded to the earth formation by means of such a syntactic epoxy resin foam, with the resin foam being extended from that depth to the surface, in order to enhance the benefits provided by the thermal insulating properties of such a foam by extending the foam into the space between the larger and smaller casings.

In completing a well in which a portion of the borehole extends across a fault, such as the fault 13 of FIG. 3A, a syntactic epoxy resin foam bonding material is preferably emplaced as shown in FIG. 3A. The positioning of portions of conventional cement 16 and 16*a* above and below the fault zone can readily be accomplished by known techniques such as staged cementing techniques. For example, casing 11 can be perforated at the depth of the top of the lower portion of cement 16*a*, a tubing string can be lowered within the casing and packed-off near the bottom and used to displace cement up the annulus between the casing and the earth formation to the depth of the perforations. After curing the element, a bridge plug can be set near the top of the cement, the casing can be perforated near the top of the depth selected for the resin foam bonding material and the latter can be injected by a procedure similar to that described above. After curing the resin the bridge plug can be moved to the top of the resin-bonded section and the above-described selective injection operations can be repeated, in order to emplace the upper portion of cement 16.

We claim:

1. In completing a well by forming a fluid-tight and mechanically strong bond between a casing string and adjacent earth formations, an improved process for increasing the endurance of such bond in a region that contains subterranean faults, which improved process comprises:

determining the depth of a fault zone encountered by the borehole of the well;

positioning within the borehole of a well a casing string that has a known compressive strength at each depth;

adjusting the composition of a liquid self-curing syntactic epoxy resin foam formulation to the extent required to cause it to produce a cured resin having a compressive strength slightly less than the compressive strength of the portion of the casing strength that is positioned adjacent to said fault zone;

forming a bond between the casing string and adjacent earth formations in said fault zone by emplacing and curing the strength-adjusted resin foam formulation along the portion of said fault zone encountered by the well and emplacing; and

forming a bond between the casing string and adjacent earth formations in other portions of the well by emplacing and curing cement in those portions.

2. The process of claim 1 in which said resin formulation is a diafoam resin formulation.

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