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(12) # EUROPEAN PATENT SPECIFICATION

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(54) **Methods of prestressing tubular apparatus.**

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US-A-3 397 745
US-A-3 511 282
US-A-3 574 357
US-A-3 693 665
US-A-4 130 301
US-A-4 340 245

(73) Proprietor: **THE BABCOCK & WILCOX COMPANY**
1010 Common Street P.O. Box 60035
New Orleans Louisiana 70160 (US)

(72) Inventor: **Reed, Stuart E.**
22756 Georgetown Road
Homeworth Ohio 44634 (US)

(74) Representative: **Cotter, Ivan John et al**
D. YOUNG & CO. 10 Staple Inn
London WC1V 7RD (GB)

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Description

This invention relates, in general, to the prestressing of tubular apparatus, for example elongated conduits for conveying hot or cold fluid, and in particular to methods of manufacturing and prestressing tubular apparatus made of two or more nested (e.g. coaxial) tubular members or tubes.

Heavy oil and tar sands represent huge untapped resources of liquid hydrocarbons which will be produced in increasing quantities to help supplement declining production of conventional crude oil. These deposits must, however, be heated to reduce the oil viscosity before it will flow to the producing wells in economical quantities. A dominant method of heating is by injection of surface generated steam in either a continuous (steam flood) or intermittent (steam stimulation or "huff and puff") mode.

When steam is injected down long injection pipes or "strings", a significant amount of thermal energy is lost to the rock overburden (150 to 2130 m or 500 to 7,000 feet) which covers the oil deposit. In the initial steam injection projects, the price of oil did not justify the prevention of this heat loss, but now with the price of oil at $30 or more a barrel, insulation systems for the well injection pipe have become economically justified.

Thermally insulated double wall piping structures are known and used, for example, as insulated steam injection tubing in oil wells, or in pipelines for carrying fluids at elevated temperatures. Such piping is disclosed, for example, in US Patent No. 3 574 357 to Alexandru et al and US Patent No. 3 397 745 to Owens et al.

It is common practice for such tubes to be prestressed in order to compensate for differential expansion of the inner and outer coaxial walls or tubes. Such prestressing is done, for example, by elongating the inner tube through such means as heating or mechanically stretching and attaching the outer tube while the inner tube is in such an elongated state. While still held in the elongated state, any heat treatment required for the attachment is completed. However, it is difficult to heat treat welds while the tubes are under stress. For this reason, it is believed that such heat treatment of the welds is not normally done in the industry, resulting in welds which are more brittle, more damage prone, and more corrosion prone.

After cool down of the heat treatment, if any, the heating or mechanical stretching is then removed and the tubes assume a state of tensile prestress on the inner tube and compressive prestress on the outer tube. While in service, carrying a hot fluid, the inner tube becomes hot and expands. This relaxes the tensile prestress before the inner tube goes into compression. In this manner, the inner tube is prevented from buckling.

In an analogous fashion, where the inner tube is to be used to convey cold fluids, the outer tube is heated or mechanically stretched before the inner tube is connected thereto.

A disadvantage of these prior approaches to prestressing double walled tubes or conduits is that the inner, outer, or both tubes (also referred to hereinafter as "tubulars") must be held in their compressed or stretched state while other manufacturing steps, such as the connection of the tubes, the heat treatment thereof and the cool-down therefrom, are accomplished.

According to the present invention there is provided a method of prestressing tubular apparatus having at least one inner tubular and an outer tubular connected to the inner tubular at at least two spaced locations along the length thereof, the method being characterised by:

heating at least a portion of one of the inner and outer tubulars to a temperature sufficient for reducing the yield strength of said portion of said one of the inner and outer tubulars to a yield strength which is less than the yield strength of the other of the inner and outer tubulars;

stretching the inner and outer tubulars by a selected amount which is beyond the yield point of said one tubular and which is not beyond the yield point of said other tubular; and

permitting said one of the inner and outer tubulars to cool while said tubulars are stretched whereby the tubular apparatus is prestressed.

The invention also provides a method of prestressing a tubular apparatus having at least one inner tubular and an outer tubular connected to the inner tubular at two spaced locations along the length thereof, the method being characterised in that the inner and outer tubulars are of materials having different yield strengths and the inner and outer tubulars are mechanically stretched so that the tubular having the lower yield strength is stretched beyond its lower yield strength.

According to a preferred embodiment of the present invention described hereinbelow, a desired state of prestress is established in a double wall tubing structure, while difficulties and disadvantages of the prior art methods are avoided or at least alleviated. According to the preferred embodiment, tubes or pipes (also referred to herein as "tubular members" or "tubulars") of the double wall tubing structure are assembled and fixedly joined to each other without prestressing. Any required heat treatment of the structure or the joint is then performed, again without any prestress condition. To achieve a prestress, the outer tube is locally heated to reduce its yield strength and then is mechanically stressed beyond its yield strength. The heat source is removed so that the mechanical stretching is rendered permanent. The outer tube is thus plastically deformed while the inner tube remains elastic. After cooling, the load establishing the mechanical stretching can be removed. Upon complete cooling, the desired prestress condition is present with a tensile force on the inner tube and a compressive force on the outer tube.

This structure is useful in conveying hot fluids such as steam in the inner tube portion.

Where cold fluids, such as liquefied natural gas, are to be conveyed, it is desirable to have a tensile prestressing on the outer type and a compressive prestressing on the inner tube. This can be achieved by heating at least a portion of the inner tube to reduce its yield strength and mechanically stressing the inner tube beyond its yield strength. The heat source is then removed. The inner tube is thus plastically deformed while the outer tube remains elastic.

The preferred embodiment of the present invention eliminates the need to maintain the elongation of one tube relative to the other tube while joining them together or the need to maintain such elongation while performing heat treatment operations. This simplifies these operations and reduces their cost, especially since heat treatment of the members connecting the tubulars is very difficult to perform while the tubulars are in a prestressed condition. The present method permits the prestressing to be performed at a convenient time in the production sequence and after any operations which may produce rejectable parts. Thus, the prestressing steps are achieved only after all previous steps have been accomplished satisfactorily. This results in a faster and less expensive production sequence and decreases the production investment in rejectable parts.

The invention will now be further described by way of illustrative and non-limiting example, with reference to the accompanying drawings, in which:

Figure 1 is a side sectional view of a double wall tube embodying the invention, showing at the top half an unstressed condition and at the bottom half a prestressed condition;

Figure 2 is a graph showing the relationship between stresses in outer and inner tubular members of the double wall tube after prestressing due to an externally applied force;

Figure 3 is a graph showing the yield strength of a typical carbon steel versus temperature;

Figure 4 is a graph showing the stress in the inner tubular member as it relates to the stress in the heated outer tubular member during the prestressing process;

Figure 5 is a graph showing the relationship between stress and strain for a typical carbon steel at 593°C (1100°F); and

Figure 6 is a graph relating the plastic (heated) length of the outer tubular member to the plastic strain needed for a given total elongation.

A description will now be given, with reference to the drawings, of a method of prestressing a double wall tube, generally designated at 10 in Figure 1, which comprises an outer tube or tubular member (hereinafter abbreviated to "tubular") 12 and an inner tube or tubular 14 which are connected to each other at axially spaced joints 16 and 18, which are preferably at or near the ends of the tubulars 12, 14.

The upper half of Figure 1 shows the double wall tube 10 before it is prestressed. In the embodiment shown, the length L_o is chosen to be 12.2 m (40 ft) and the material, at last of the outer tubular, is chosen to be carbon steel.

The lower half of Figure 1 shows the stretched and prestressed state of the double wall tube 10. The length has been increased by an amount ΔL.

For this example, suppose that the tubulars are chosen to be:

Outer tubular: 12.2 m (40 ft) long
114.3 mm (4.5 in) outside diameter (OD)
6.88 mm (0.271 in) wall
carbon steel
379 MPa (55 klbf/in^2 or "KSI") room temperature yield strength
Area of cross section=23.23 cm^2 (3.600 in^2);

Inner tubular: 12.2 m (40 ft) long
73.0 mm (2.875 in) outside diameter (OD)
5.51 mm (0.217 in) wall
carbon steel
552 MPa (80 KSI) room temperature yield strength
Area of cross section=11.69 cm^2 (1.812 in^2);

and that the desired level of prestress in the inner tubular is 172 MPa (25 KSI) tension. At isothermal conditions (same temperature on both tubulars), the corresponding stress in the outer tubular is 86.9 MPa (12.6 KSI) compression.

The inner tubular 14 is inserted into the outer tubular 12, the tubulars are welded together at each end with no prestress, and the welds are heat-treated as required.

To produce the desired condition of prestress, the outer tubular 12 is first heated to 593°C (1100°F) over a length of 305 mm (12 in). A typical stress-strain curve for a carbon steel at this temperature is shown in Figure 5. Both tubulars 12, 14 are then subjected to a load of 1.209 MN (271.8 Kips (thousand pounds force)). This load produces a stress in the inner tubular 14 of 517 MPa (75 KSI) tension (elastic) and in the outer tube of 260 MPa (37.75 KSI) tension. In the heated portion of the outer tubular 12, this stress produces 5% plastic strain, while in the cooler portion, the stress is still elastic. The 5% plastic strain over a 305 mm (12 in) length results in a total overall length increase of 15.2 mm (0.6 in). When the outer tubular 12 cools to about 427°C (800°F), the load is removed. When the outer tubular 12 has cooled to room temperature, the 15.2 mm (0.6 in) length increase results in the desired stress state: 172 MPa (25 KSI) tension in the inner tubular and 86.9 MPa (12.6 KSI) compression in the outer tubular 12.

In its prestressed condition, the inner tubular 14 thus is exposed to an incremental stress σ of 172 MPa (25 KSI). Factoring in the difference in area of the inner and outer tubulars, this corresponds to a compressive stress on the outer tubular of $\sigma=86.9$ MPa (12.6 KSI).

Figure 2 shows the relationship between the incremental stresses on the inner and outer tubulars with a maximum on the outer tubular being 259 MPa (37.5 KSI). The maximum level is established since above this level the yield strength for the inner tubular is approached.

Figure 3 shows the relationship between temperature in degrees Celsius and Fahrenheit and yield strength for a typical carbon steel used for the outer tubular (e.g. 8260 annealed steel). In order to reduce the yield strength to less than 259 MPa (37.5 KSI), a temperature of at least about 538°C (1000°F) is required. In fact, the yield strength must be somewhat lower since the outer tubular 12 must not only yield but it must also undergo some strain.

Figure 4 illustrates how the force applied to the outer tubular 12 initially effects a linear increase in length. Once the yield point is reached for the outer tubular 12, however, the increase becomes non-linear and corresponds to plastic deformation of the outer tubular. With a release of the load, the prestress on the inner tubular 14 decreases until it reaches the desired level of 172 MPa (25 KSI). This is a condition which is in equilibrium with the 86.9 MPa (12.6 KSI) compressive prestress on the outer tubular 12.

By selecting the temperature and the heated length for the outer tubular 12, the prestress on the inner tubular 14 can be controlled. The stress (strain state) at the completion of yielding must fall on the curve shown in Figure 2. Once the stress-strain curve for the outer tubular 12 is known, the heated length can be determined, as can the temperature of the operation.

As long as the temperature is such that the minimum yield of the outer tube is greater than 86.9 MPa (12.6 KSI), it is probably not necessary to hold the prestress once the yielding has occurred. This is assuming that the heated length is short enough as not to buckle.

The required plastic deformation (ΔL) is about 15.2 mm (0.6 in) with the plastic strain needed as a function of the heated length being shown in Figure 6.

The double wall tube described above is useful where the inner tubular 14 is intended to convey heated substances such as steam. Where the inner tubular 14 is intended to convey cold substances such as liquefied natural gas, the inner tubular 14 rather than the outer tubular 12 can be heated and stretched.

As an alternative measure, the material making up the inner and outer tubulars can be chosen to have different yield strengths, with the tubular to be plastically deformed having the lower yield strength.

It is noted that two or more inner tubulars or tubes may be provided within the outer tubular or tube and may be prestressed to different levels. This is possible by providing the tubulars with different yield strengths. The inner tubulars may be axially spaced and aligned, disposed one next to the other or one within the other.

It is also advantageous to insulate the annular space formed between the inner and outer tubulars. This can be done by providing fibres or layered insulation which is preferably wrapped around the inner tubular. A thermal barrier can also be established by evacuating the annular space. The evacuated space may be used in conjunction with the fibrous or layered insulation, or alone. To maintain the vacuum over a prolonged period of use for the tubing, a getter material is provided, preferably at a high temperature location within the annular space, that absorbs such gases. Such a getter material is preferably adjacent the inner tube and activatable at a temperature betwseen 204°C and 371°C (400°F and 700°F). Gases which may leak into the vacuum include hydrogen formed by corrosion on the outer tubular migrating through the outer tubular and such gases as nitrogen and carbon monoxide outgassed from the material of the inner tubular.

In an alternative embodiment of this invention, the inner tubular 14 is composed of a material which has a higher yield strength than the material of the outer tubular 12, and the stress in the inner tubular 14 is allowed to exceed its yield strength while the outer tubular 12 is stretched such that its yield strength is exceeded. This results in a prestressed condition which is limited by the difference in the yield strengths of the tubulars.

Claims

1. A method of prestressing tubular apparatus having at least one inner tubular (14) and an outer tubular (12) connected to the inner tubular at at least two spaced locations (16, 18) along the length thereof, the method being characterised by:

heating at least a portion of one of the inner and outer tubulars (14, 12) to a temperature sufficient for reducing the yield strength of said portion of said one of the inner and outer tubulars to a yield strength which is less than the yield strength of the other of the inner and outer tubulars;

stretching the inner and outer tubulars (14, 12) by a selected amount which is beyond the yield point of said one tubular and which is not beyond the yield point of said other tubular; and

permitting said one of the inner and outer tubulars to cool while said tubulars are stretched whereby the tubular apparatus is prestressed.

2. A method according to claim 1, including heating and mechanically stretching the outer tubular (12) so as to apply a compressive prestressing thereto and so as to apply a tensile prestressing to the inner tubular (14).

3. A method according to claim 1, including heating and stretching the inner tubular (14) so as to apply a compressive prestressing thereto and so as to apply tensile prestressing to the outer tubular (12).

4. A method of prestressing a tubular apparatus having at least one inner tubular (14) and an outer tubular (12) connected to the inner tubular at two spaced locations (16, 18) along the length thereof, the method being characterised in that the inner and outer tubulars (14, 12) are of materials having different yield strengths and the inner and outer tubulars are mechanically stretched so that the tubular having the lower yield strength is stretched beyond its lower yield strength.

Patentansprüche

1. Verfahren zum Vorspannen von Rohrleitungen mit wenigstens einem inneren Rohr (14) und einem äußeren Rohr (12), das mit dem inneren Rohr an wenigstens zwei voneinander beabstandeten Stellen (16, 18) entlang seiner Länge verbunden ist, dadurch gekennzeichnet, daß man wenigstens einen Teil des inneren oder äußeren Rohres (14, 12) auf eine ausreichende Temperatur erhitzt, um die Streckgrenze dieses Teils des inneren oder äußeren Rohres bis zu einer Streckgrenze, die geringer als die Streckgrenze des anderen der inneren und äußeren Rohre ist, zu vermindern, das innere und äußere Rohr (14, 12) in einer ausgewählten Menge, die jenseits der Streckgrenze des einen Rohres liegt und nicht jenseits der Streckgrenze des anderen Rohres liegt, streckt und das innere bzw. äußere Rohr abkühlen läßt, während die Rohre gestreckt sind, wodurch die Rohrleitung vorgespannt wird.

2. Verfahren nach Anspruch 1, bei dem das äußere Rohr (12) derart erhitzt und mechanisch gestreckt wird, daß es einer kompressiven Vorspannung unterzogen wird und das innere Rohr (14) einer Dehnungsvorspannung unterzogen wird.

3. Verfahren nach Anspruch 1, bei dem das innere Rohr (14) derart erhitzt und gestreckt wird, daß es einer kompressiven Vorspannung unterzogen und das äußere Rohr (14) einer Dehnungsvorspannung unterzogen wird.

4. Verfahren zur Vorspannung von Rohrleitungen mit wenigstens einem inneren Rohr (14) und einem äußeren Rohr (12), das mit dem inneren Rohr an wenigstens zwei voneinander beabstandeten Stellen (16,18) entlang seiner Länge verbunden ist, dadurch gekennzeichnet, daß das innere Rohr und das äußere Rohr (14, 12) aus Materialien mit unterschiedlichen Streckgrenzen besten und das innere und äußere Rohr derart mechanischen gestreckt werden, daß das Rohr mit der niedrigeren Streckgrenze über seine niedrigere Streckgrenze hinaus gestreckt wird.

Revendications

1. Procédé de précontrainte de dispositif tubulaire comportant au moins un élément tubulaire intérieur (14) et un élément tubulaire extérieur (12) raccordé à l'élément tubulaire intérieur en au moins deux emplacements (16, 18) espacés sur la longueur de celui-ci, le procédé étant caractérisé en ce que:

on porte une partie au moins d'un premier des éléments tubulaires intérieur et extérieur (14, 12) à une température suffisante pour ramener la limite élastique apparente de ladite partie dudit élément tubulaire intérieur ou extérieur à une valeur inférieure à la limite élastique apparente des autres des éléments tubulaires intérieur et extérieur;

on tend les éléments tubulaires intérieur et extérieur (14, 12) dans une mesure choisie qui dépasse le point d'écoulement dudit premier élément tubulaire et non le point d'écoulement de l'autre susdit élément tubulaire; et

on laisse ledit premier des éléments tubulaires intérieur et extérieur refroidir pendant que lesdits éléments tubulaires sont tendus ce qui assure le précontrainte du dispositif tubulaire.

2. Procédé selon la revendication 1, comportant le chauffage et la tension mécanique de l'élément tubulaire extérieur (12) opérés de façon à appliquer à celui une précontrainte de compression et à appliquer à l'élément tubulaire intérieur (14) une précontrainte de traction.

3. Procédé selon la revendication 1, comportant le chauffage et la tension de l'élément tubulaire intérieur (14) opérés de façon à appliquer à celui-ci une précontraite de compression et à appliquer à l'élément tubulaire extérieur (12) une précontrainte de traction.

4. Procédé de précontrainte d'un dispositif tubulaire comportant au moins un élément tubulaire intérieur (14) et un élément tubulaire extérieur (12) relié à l'élément tubulaire intérieur en deux emplacements (16, 18) espacés sur sa longueur, le procédé étant caractérisé en ce que les éléments tubulaires intérieur et extérieur (14, 12) sont en des matériaux ayant des limites élastiques apparentes différentes et les éléments tubulaires intérieur et extérieur sont tendus mécaniquement de façon que l'élément tubulaire ayant la limite élastique apparente la plus faible se trouve tendu au-delà de sa limite élastique apparente plus faible.

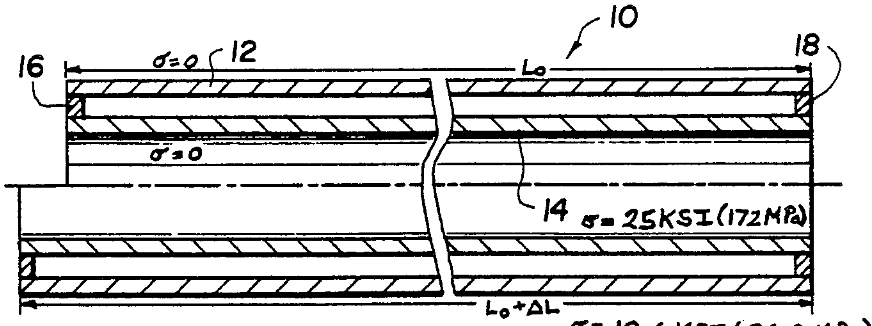

10
16
σ=0
12
Lo
18
σ=0
14
σ= 25KSI (172MPa)
Lo+ΔL
σ= 12.6 KSI (86.9 MPa)

FIG. 1

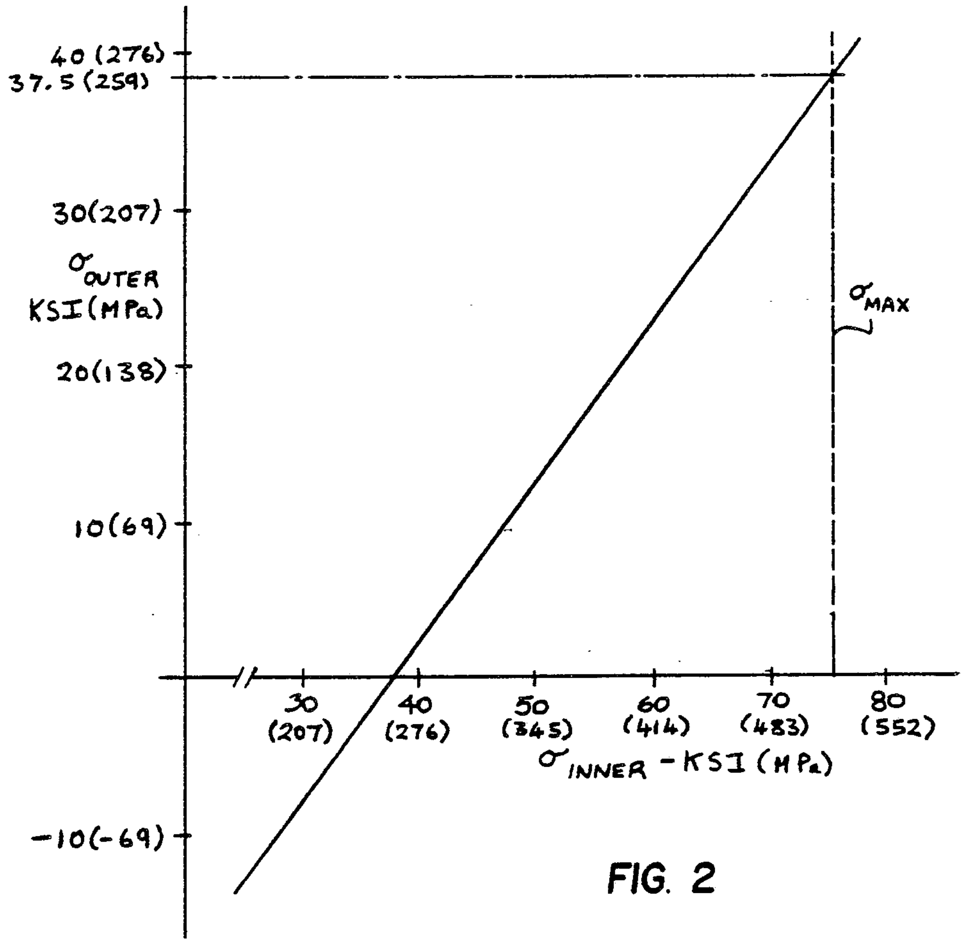
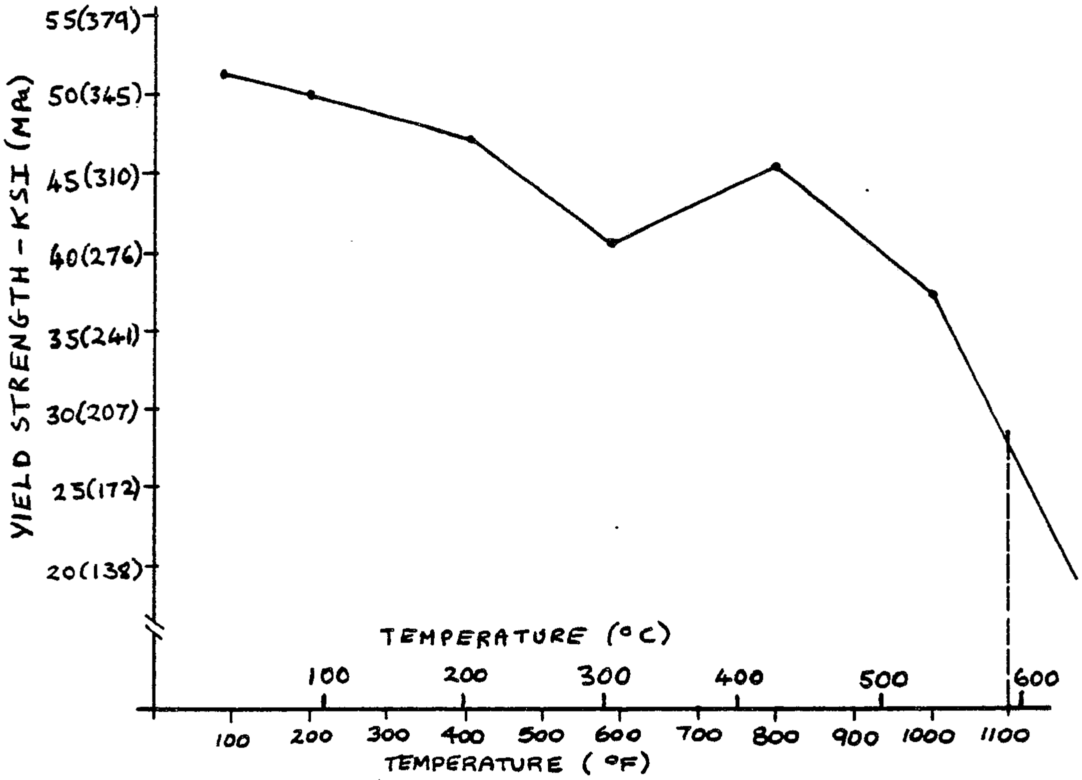

40 (276)
37.5 (259)
30(207)
σ OUTER
KSI (MPa)
20(138)
10(69)
-10(-69)
30 (207)
40 (276)
50 (345)
60 (414)
70 (483)
80 (552)
σ INNER - KSI (MPa)
σ MAX

FIG. 2



YIELD STRENGTH VS. TEMP.

FIG. 3

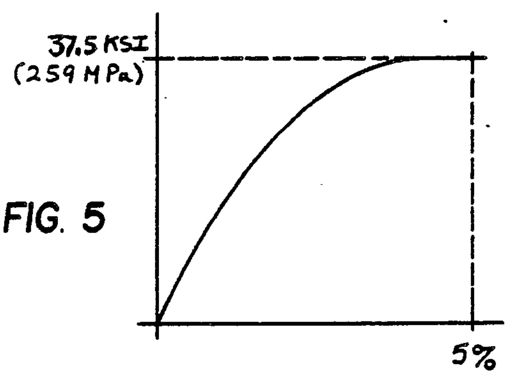


FIG. 5

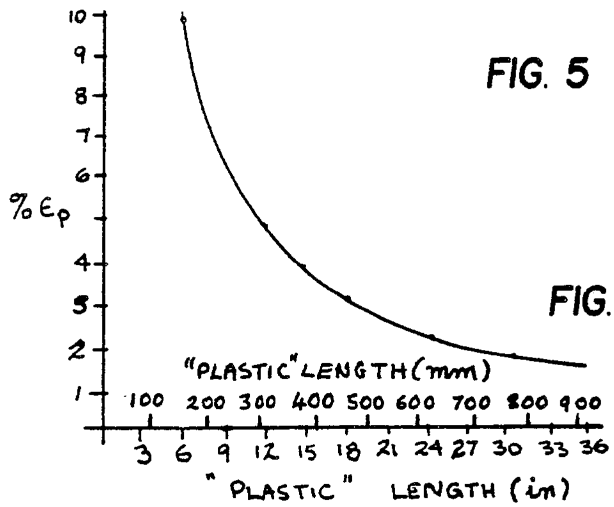
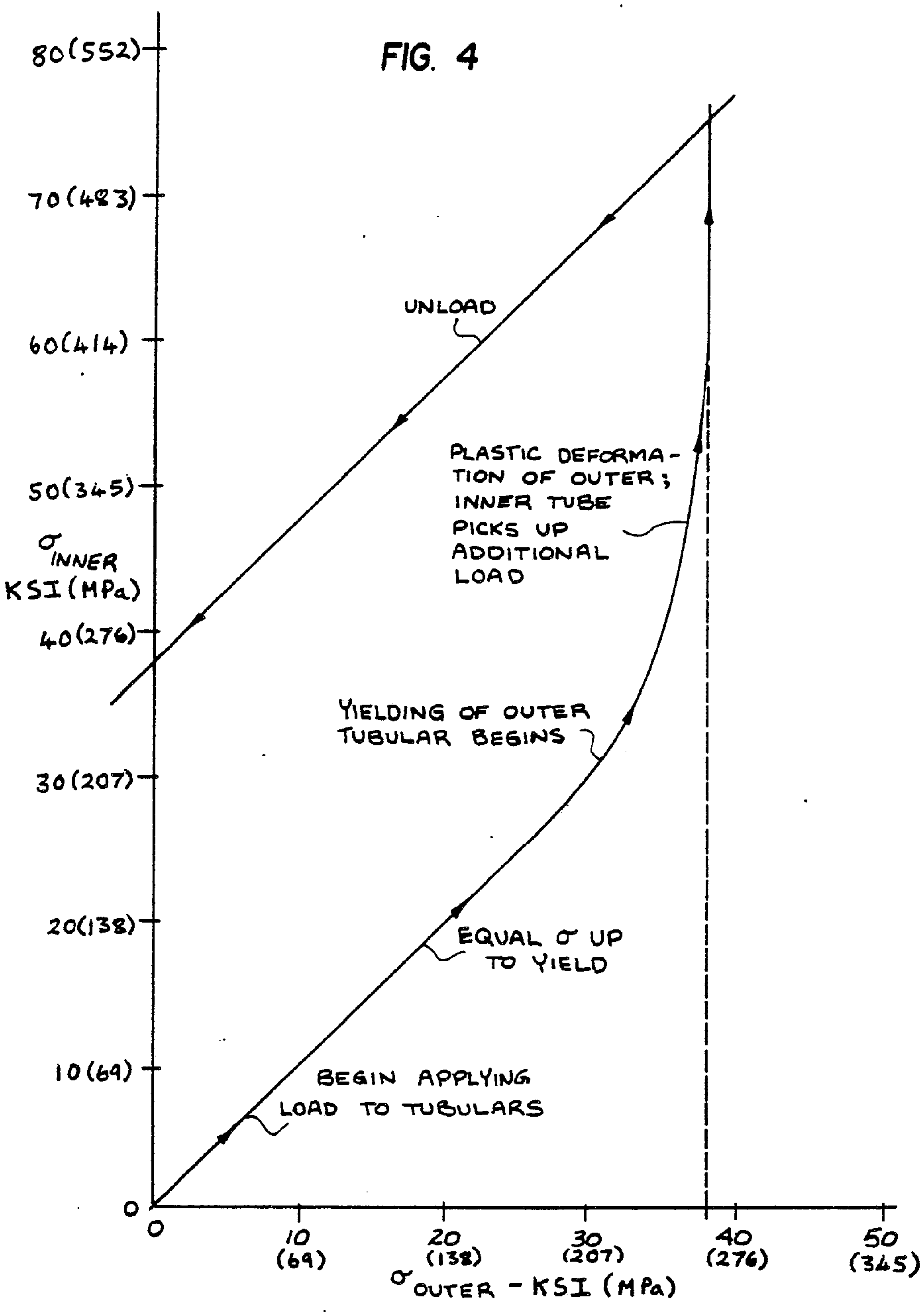


FIG. 6

FIG. 4


80(552)
70(483)
60(414)
50(345)
σ INNER KSI (MPa)
40(276)
30(207)
20(138)
10(69)
0
UNLOAD
PLASTIC DEFORMATION OF OUTER; INNER TUBE PICKS UP ADDITIONAL LOAD
YIELDING OF OUTER TUBULAR BEGINS
EQUAL σ UP TO YIELD
BEGIN APPLYING LOAD TO TUBULARS
0
10 (69)
20 (138)
30 (207)
40 (276)
50 (345)
σ OUTER - KSI (MPa)