Technique of Fabrication and Control of Centrifugally Cast Steel Tubes for Jack-up Elements

By
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Engineers have to compare many materials prior to selecting any when carrying out the realization of an offshore platform, the prevailing selection criteria being strength level, minimum mechanical steel properties, manufacturing processes affecting the quality, thus the safety level of the structure, shape of product, assembly process, etc.

Results of experiments presented in this document show that it is now possible to obtain through centrifugal casting, pipes of high quality and high mechanical properties to be used for up-to-date leading offshore techniques and their use in the construction of Jack-ups has the advantages of very high mechanical properties in an unusual diameter/thickness ratio, very fine strength/ductility ratio at low temperature, perform weldability, dimensional accuracy allowing an easy assembly and quality level 1, from the standpoint of soundness and metallurgy.

For certain movable structures of the Jack-Up type, various investigations showed that it may be interesting to use high-resistant steel. The horizontal casting technique associated to a proper heat-treatment allows the production of heavy-wall tube with high mechanical characteristics to be used in this industry.

This paper describes:

—the principle of horizontal casting of steel applied to the manufacture of heavy-wall tubes and in particular to jack-up elements,

—special offshore steel grades with low carbon (c \( \leq 0.08\% \)) of Mn-Mo-Ws type and with variable Nickel content (0 to 3\%), elaborated to cover the whole range of yield strengths between 48,000 and 100,000 Psi with guaranteed impact values at \(-40^\circ\)C and complying with all the particular offshore specifications.

—the metallurgical study of the 3% Ni grade (Centrisshore V) with an yield strength superior to 100,000 Psi, the development of austenitic grain, the quenched, intercritical quenched and tempered states, leading to a two-phased bainite-austenite structure.

—the properties of industrial tubes.

—the study of weldability of the Centrishore V grade.

—the industrial realization of jack-up legs by the centrifugal casting process, in Centrishore V grade, with tubes having an outside diameter of 800 mm, a thickness varying from 40 to 70 mm, a length up to 18 m: specifications, casting, heat-treatments, machining, welding and controls. Utilization of these elements by the constructor.

As a conclusion, this paper reveals the advantages of the centrifugal casting technique applied to the production of large size thick pieces as well as the possibilities of development.

During the last few years, many efforts have been spent throughout the world to develop weldable steels with a high yield strength and with transition temperature below minus 40\(^\circ\)C, for manufacture of pipes and offshore platforms components having to withstand very severe climatic conditions. Among the steels liable to be used in such conditions, the Mn-Mo steels with special Nb additions have the preference but their usual type of elaboration by controlled rolling technique limits the thickness. It was a drawback to produce through standard techniques, high-resistant steel pipes in the requested diameter/thickness relationship that would be reliable and economical. The centrifugal casting of steel solved this problem.

Principles of centrifugal casting

The centrifugal casting consists in rotating a mould while filling it with a liquid metal (Fig. 1). The centrifugal force which appears once the mould is rotating around its axis, radially to the rotating axis, is used to fill regularly the metal in the mould cavity. The usual rotational speed employed results in forces of 100 g operating in the bore of the mould. Such conditions give an homogeneous structure.

Either for metallurgical reasons (grade, solidification rate, etc.) or for economical reasons (quantity, sizes, etc.), two types of mould are generally used. The mould can be either in sand or in metal. For the production of the herein mentioned jack-up elements, the tubes have been cast in metallic moulds,
High-resistant commercial steel grades

All the metallurgical studies performed by the authors have led to the elaboration of five commercial low carbon steel grades. The chemical compositions and the guaranteed properties have been studied and these grades developed to cover an yield limit ranging from 48,000 to 115,000 psi with toughness values down to minus 40°C. This figure also describes the quality of centrifugally cast steels compared to other manufacturing processes for, in any sampling direction, the reductions of area are all above 40%.

One of the most interesting development concerns the Centrishore V-steel grade, with which were manufactured the legs of seven jack-ups for C.P.M. Heat-treatments enable to produce either type A or B grade with an identical chemical composition.

Metallurgical study of the Mn-Mo steels conducted previously showed an yield limit ranging from 56,300 to 71,000 psi, of an acicular ferritic structure. An additional increase of the yield limit may be achieved by a bainitic or martensitic transformation. The simultaneous achievement of a high yield limit and a good toughness at -40°C implies: chemical composition, cooling kinetics, heat-treatments, which are parameters necessitating a very fine adjustment.

Owing to segregation difficulties during the centrifugal casting, to toughness and weldability problems, the carbon value is always maintained at a low level inferior to 0.10% even 0.09%. The loss in strength should be compensated; a wise compromise is needed between Ni, Mn, Mo, Si values, dispersoid elements Ti, Al, Nb, V and hydrogen values.

The primary grain size plays a leading role in the achievement of the mechanical characteristics of this type of steel. With the aforementioned composition, it is possible to obtain the whole range of primary grains according to the cooling kinetics in the process of solidification. Significant Ni and Mn corings may be observed at the as-solidification state; they are due to the solidification process and the chemical composition (Fig. 2). In order to obtain a primary grain which, after heat-treatment, will have all the required mechanical properties, a rapid and controlled cooling will have to be carried out. Therefore, a thorough knowledge of all the centrifugal casting parameters is needed: mould thickness, internal coating, cooling system, etc.
Heat treatments

For this type of alloy, the scope of heat-treatments is various. First of all, the austenizing at high temperature should allow the homogenization of the structure, i.e., the reduction of coring and the adjustment of the austenitic grain size prior to quenching within a range compatible with the results to achieve, and redissolve a part of precipitates such as the aluminum nitrides and niobium carbonitrides needed for tempering.

Development of the $\gamma$ grain size—In the case of an one-hour austenitizing at temperature below 1100°C, the $\gamma$ grain size ranges from 10 to 100 $\mu$m. From 1100°C, the size of grain increases. In the case of a double treatment, the size of grain ranges from 5 to 50 $\mu$m, whatever the temperature of the first treatment may be, if the temperature of the second austenitizing does not exceed 1050°C. Above this temperature, the $\gamma$ grain increases.

Development of the mechanical properties—After austenitizing treatments at temperatures ranging from 950 to 1150°C, followed by quenching at 4°C/s and one-hour tempering at 560°C, an increase of the yield limit with the austenitizing temperature could be noticed. This is explained by an increase of the dissolution rate of carbides and carbonitrides with the austenitizing temperature. But in all cases, the toughness remains inferior to the agreed limits at -40°C. After a double-treatment, the refining of the grain slightly increases the yield strength but it does not improve significantly the toughness which is too low at -40°C. The tempering temperature has to be increased to obtain a greater toughness, but the Al alloy temperature being low (615°C), an intercritical treatment (between A1 and A3) will have to be carried out instead of tempering.

Therefore, after an one-hour intercritical treatment at 650°C, the toughness at -40°C reaches values superior to 40 J/cm$^2$, but the toughness improvement is made to the detriment of the yield limit which loses 100 MPa. This is explained by the formation in the intercritical field of an austenite with a very high content of gamageneous components that stabilize the austenite till it reaches the ambient temperature. This quantity of austenite untransformed at ambient temperature influences both the toughness and the yield limit levels:

—If the quantity of austenite is too small, the toughness is not admitted,

—If the quantity of austenite is too important, the yield limit is too low.

It is of top importance to control the austenitizing rate formed during the intercritical treatment. Therefore, a thorough knowledge of the treatment parameters (temperature, time) and of the initial state of steel on the austenite quantity formed, is needed.

Influence of time and temperature

The curves $\% \gamma$ formed in function of time at different temperatures (Fig. 3) show that at a given temperature, and at the beginning of the reaction, the formation rate of austenite is very rapid, especially if temperature increases above A1. They show on the other hand that the quantity of austenite formed at equilibrium, is a linear function of temperature.
To the transformation of the quantity of austenite formed in function of the temperature, another transformation takes place, its chemical composition. The higher the temperature, the greater the quantity of austenite formed in the intercritical area and the poorer in gamma-geneous elements it becomes.

If one considers that cooling after intercritical treatment occurs in still air, the products formed in this austenite will be very different. At temperatures above A1, only little austenite is formed, it is therefore rich and stable at ambient temperature. The alloy is constituted of a mixture (α + γ) tempered + γ residual and the intercritical treatment leads to a softening. At higher temperatures, the quantity of austenite formed in the intercritical area increases. The austenite will be less rich and may be transformed, during cooling, into martensite, bainite or perlite. Sophisticated mixtures may be obtained once ambient temperature has been reached:

(α + γ) temperings + M + γ residual
(α + γ) temperings + M + B, etc.

The softening of the original structure and the concurrent hardening due to the formation of the quenching products in the austenite formed in the intercritical area, make it difficult to adjust the mechanical properties.

Measurements made at 645°C on the same steel taken in the as-solidified and in the quenched states, show that not only the austenitized kinetics are different but that a significant difference remains at equilibrium. The tempered state, more homogeneous, leads to the formation of a larger quantity of austenite. It seems important that the solidification conditions which have an effect on the cooling degree should be well controlled to ensure a good reproducibility during heat-treatments. In short, the quantity of austenite formed is function of the temperature, holding time and initial state of material. As the chemical composition of austenite develops with the quantity of austenite formed, it leads to a development of the quantity and nature of phases formed during cooling in the austenite coming from the intercritical area, with all the consequences it may have on mechanical characteristics.

Morphology of steel

This study has been carried out on a Centrashore V-steel treated in industrial conditions. The CCT diagram (Fig. 4) shows that, for this alloy, the proeutectoid ferrite and perlite areas are rejected toward high times. The transformation of austenite to bainite starts at 510-520°C, at a rate of 4°C/s. The austenite is concentrating while the bainite transformation occurs. At 375°C, the transformation is completed. We are now in presence of bainitic ferrite and austenite. The austenite does not undergo any transformation from 375 to 325°C. From 325°C, the post-bainitic austenite is transformed to martensite. The difference of the Ms post-bainitic austenite temperature and the Ms temperature of the alloy (80°C) shows the concentration of the post-bainitic austenite. It is to be noticed, moreover, that for rates from 2°C/s to 1°C/s, there is no significant development of the nature of phases formed and that the temperature Ms of the post-bainitic austenite remains nearly stable.

At the quenched state, the alloy, when examined with an electronic microscope (Fig. 5), shows a very fine structure of bainitic ferrite (Fig. 5) shows a very fine structure of bainitic ferrite lath separated by a thin border of untransformed martensite and austenite.
In the largest ferrite cells (Fig. 6), the first ones formed at higher temperatures, acicular carbides having an orientation relationship with ferrite, may be noticed. This carbide has been indentified as being hexagonal carbide $\varepsilon$. Quenched state, then intercritical treatment: The treatment is intercritical only for the interdendritic areas highly concentrated with gammaogenous elements.

Zones poor in gammaogenous elements (Fig. 7), undergo only a tempering. The bainitic ferrite is slightly recrystallized and the presence of carbides of different types is to be observed: allowed cementite and molybdenum carbides. In rich zones (Fig. 8) which, alone undergo the intercritical treatment, the austenite formed at interfaces between the laths of ferrite bainite where the mixture $\alpha + \gamma$ already existed at the as-quenched state. Then the austenite developed to the detriment of bainitic ferrite, resulting in very large austenite cells. A true bi-phased structure $\alpha + \gamma$ has been achieved as shown on next page (Fig. 9).

Fig. 6—Presence of carbide $\varepsilon$ in ferrite cells at quenched state.

Fig. 7—Zone rich in $\gamma$ quenched state + intercritical tempering.

Fig. 8—Zone poor in $\gamma$ quenched state + intercritical tempering.

The studies in laboratory allowed the adjustment of the structure, therefore the mechanical properties of the Centrishe V alloy. A manufacturing cycle was elaborated including all the important parameters: cooling rate, analysis, complete heat-treatment allowing for each size of tube (diameter, thickness, etc.) to obtain all the mechanical properties and soundness for its utilization as jack-up legs.

Properties of Centrishe V pipes

Many tests have been carried out on commercial pipes while agreement procedures by Det Norske Veritas were perfected and during fabrication. It is not important to summarize the results obtained; most of them are in compliance with the properties for the conventional characteristics or almost similar for particular characteristics such as COD, Pellini tests, etc. It would make more sense to show the results obtained on some commercial realizations as tabulated on next page (Fig. 10).

From these results a preliminary remark may be made: the important toughness variation between pipe A and the other pipes is due to a different heat-treatment. A heat-treatment on pipe A identical to the one performed on pipes B, C, D gives a KV value at $-40^\circ$C of 71 joules. Toughness levels of the A type are not required by the engineering and economical considerations led to select the B, C and D treatments. The intrinsic possibilities of this materials may nevertheless be noticed. Furthermore, a too sudden increase of the KV value is not recommended as may be seen later on. It is interesting to find out how the mechanical properties develop in offshore applications versus time; thanks to laboratory tests, the ageing phenomena may be examined. Thus, toughness tests may be performed on a sample main-
sufficient nickel content, that is the case of this type of steel.

The "Nil-ductility transition temperature" has been determined on pipes A, B, and C according to ANSI/ASTM E 208-69 Standards. The 500 mm long, 30 mm wide and 25 mm thick specimens are complying with the Standard PI type. The weld beads have been deposited on the inside of the pipe and have been performed with an electrode Murex Hordex diam. 4 mm (welding current 140A). The determination of fracture impact (drop ball of 40 Kg from a height of 4 m), the notch depth, the distance between supports, the maximum strain, the condition of temperature setting are in compliance with Standard.

From results obtained on A, B, C pipes without drawing hasty conclusions, it should however be emphasized that pipe A, with the highest toughness level at -40°C has lowest NDT. That pipe undergoes a heat-treatment to obtain a structure with a high impact capacity up to a certain temperature level. The B, C, D pipes structure has a lower impact strength capacity but temperature to be reached should be much lower to undergo fracture during distortion. The choice or compromise depends on the research departments according to the required properties of the elements to be welded.

The COD tests were conducted in accordance with Standard BS 5762-1979 on three-point bending.
The square section specimens correspond to the subsidiary specimens. They are provided with a notch perpendicular to the pipe thickness of 0.3W including the machined notch and the fatigue crack obtained with a maximum R of 38 MPa m and a ratio R = 0.1. The test fracture on specimens have been effected with static load at -20°C. The COD value (crack displacement) have been calculated from Vp values obtained from the various recorded curves P = f (V).

As a matter of fact, the pipe with a high fracture impact level at -20°C on KV is the one that has the highest COD values. This is due to the type of structure fairly different, i.e. the size of the bainitic lath, the distance between laths and the ferritic rate.

Weldability of V steels

One of the major problem concerning the weldability of steels is, without any doubt, the cracking possibility. As a matter of fact, it is well known that a crack may be the beginning of a dramatic failure and the catastrophic results caused by such a failure can be easily imagined, when the relevant parts are used for high safety level constructions such as those having to do with prospect and exploitation of offshore hydro-carbons.

The welding of micro-alloyed steels must obviously take into account the numerous type of concerns, i.e. under-bead hardness or cold cracking problems, toughness or more generally speaking, the ductility of both the molten metal and the heat-affected zone, the sensitivity of the various structures of the welded joint to the initiation and propagation of cracks under variable stresses. Many studies are necessary to determine all the parameters affecting the operational and metallurgical weldability of given steel. The following parameters: welding conditions, types of filler material and in the case of electrode welding, the hydrogen content, cooling rates will help to draw up operating procedures which ensure reliability to the users thanks to a safe assembly process.

For an user, i.e. usually a company, involved in the welding operations performed in different conditions, it is of top importance to know about the cold cracking risk of steel. The implants method, developed by H. Granjon is presently widely improved because it is simple compared to the RRC method and because of the reliability of the results. This technique has been used to test the Centrishore V steel because the notion of equivalent carbon, often used as a criterion of cracking risk and related to the determination of under-bead hardness is not a very reliable notion.

Laboratory simulation test

As the minimum pre- and post-heating time and temperature are determined to prevent the cold cracking risk, it is necessary to define the other operating welding conditions in order to obtain in molten zone and in affected zone the required mechanical characteristics as well as a soundness compatible with the expected applications and still meeting the most severe economical requirements. It is very important to know how the toughness of the molten metal develops and the heat-affected zones versus cooling rates, i.e., the operating conditions. These developments can be presented under two forms:

- KCV (J/cm²) or KV (joules) according to temperature for given arc energies, i.e. given cooling rates.

The cooling rate/arc energy relationships have been determined by direct measurement during welding for the specified operating conditions. All the tests have been carried out on O.D. 800 tubular elements and of 21 mm thickness, and in multi-passes welding. The weldings have been carried out with the Union-melt process with Oerlikon Fluxweld 42 wire of 32 mm diameter and Flux OP 121 TT 300°C.

According to preheating temperatures, inter-passes temperatures and arc energy, it is quite obvious that the 800-300°C cooling rate may vary and thus the toughness characteristics may develop, graphic charts may be established and the conditions of commercial manufacturing may be optimized for every case. As an example, the results obtained on a prototype weld for D.N.V. agreement of the Centrishore V A steel grade are:

- Welded elements 800 × 724 mm
- Chamfers V 60°C with 2 mm root

Weld parameters

- Preheating: 100°C
- Root passes: 2 passes Tenacito 75
  Diameter: 3.2 mm
  Voltage: 1st pass 21 V
          2nd pass 23 V
  Current: 95/125 A
  Speed travel: 7 cm/mm
The square section specimens correspond to the subsidiary specimens. They are provided with a notch perpendicular to the pipe thickness of 0.3W including the machined notch and the fatigue crack obtained with a maximum K of 38 MPa m and a ratio R = 0.1. The test fracture on specimens have been effected with static load at −20°C. The COD value (or crack displacement) have been calculated from Vp values obtained from the various recorded curves P=f (V).

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For an user, i.e. usually a company, involved in the welding operations performed in different conditions, it is of top importance to know about the cold cracking risk of steel. The implants method, developed by H. Granjon is presently widely improved because it is simple compared to the RRC method and because of the reliability of the results. This technique has been used to test the Centrisnare V steel because the notion of equivalent carbon, often used as a criterion of cracking risk and related to the determination of under-bead hardness is not a very reliable notion.

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−C (TK 40 joules) according to the arc energy or to the cooling rate between 800 and 300°C.
−KCV (J/cm²) or KV (joules) according to temperature for given arc energies, i.e. given cooling rates.

The cooling rate/arc energy relationships have been determined by direct measure during welding for the specified operating conditions. All the tests have been carried out on O. D. 800 tubular elements and of 21 mm thickness, and in multi-passes welding. The weldings have been carried out with the Unison-melt process with Oerlikon Fluxasig 42 wire of 32 mm diameter and Flux OP 121 TT 300°C.

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<table>
<thead>
<tr>
<th>Welded elements</th>
<th>800 x 724 mm</th>
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<tbody>
<tr>
<td>Chamfers</td>
<td>V 60°C with 2 mm root</td>
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<table>
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<tr>
<th>Preheating:</th>
<th>100°C</th>
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<tbody>
<tr>
<td>Root passes:</td>
<td>2 passes Tenacito 75</td>
</tr>
<tr>
<td>Diameter:</td>
<td>3.2 mm</td>
</tr>
<tr>
<td>Voltage:</td>
<td>1st pass 21 V</td>
</tr>
<tr>
<td></td>
<td>2nd pass 23 V</td>
</tr>
<tr>
<td>Current:</td>
<td>95/125 A</td>
</tr>
<tr>
<td>Speed travel:</td>
<td>7 cm/min</td>
</tr>
</tbody>
</table>
Automatic filling (Unionmelt):
- Oerlikon Fluxcord 42 wire
- Flux OP 121 TT

Diameter of wire: 3.2 mm.

The first two passes:
- Voltage: 28 V
- Current: 400 A
- Speed travel: 4 cm/mm
- Heat input: 14.9 kJ/cm
- Temperature between passes: 150/170°C.

Notch toughness

Those tests have been performed in compliance with the DNV recommendations in the weld, in the HAZ, at 1 mm, 3 mm and 5 mm from the melting line.

The COD tests have been performed in accordance with BS Standard 5762-1979 on three-point bending as mentioned previously about steel qualifications.

Various controls:
- The bending of parallel branches revealed no crack or crack initiations.
- The radiographic and ultrasonic tests showed no redhibitory defect.
- The hardness relationship shows in no way a hardness over 336 HV3.

The centrifugally cast element in Centriform V A and B have been used for the manufacture of self-elevating platforms after having been accepted by DNV, in the North Sea. For this type of platform the bracings with or without racks having a thickness over or equal to 28 mm and the thick sections of the horizontal bracings are manufactured in centrifugal cast steel.

The sections of about 15 m used for the manufacturing of bracings are constituted of butt-welded tube units of approximately 5 m, with a uniform or variable thickness, the butt welds never being located within the welding spots of bracings.

Extracts of manufacturing specifications for 800 mm Centriform V A Sections

The first platforms have been manufactured in Centriform V A steel. Since approximately mid-1981, all the platforms have been manufactured in Centriform V B.

Reference documents for the manufacturing and control:
- DNV Rules for Classification of steel ships
- AFNOR Standards A60.305 and A64.311
- ASME Code sections V and VIII
- AWS Code D, 1, 1.80
- Rules for the design construction and inspection of offshore structure DNV 1977
- IS/JS319-21
- Surface calibration Laboratory of Munitions
- ASTM E71
- IIW's reference collection for welding radiography
- Stipulations regarding ultrasonic inspection of weld connections (DNV-1978).

Properties of sections:
- Dimensions: in accordance with Customer's Nomenclature
- Straightness: maximum deflection 8 mm/15 m
- Surface finish: machined
- Out-of-roundness [Φ B - Φ A] ≤ 3 mm
- Concentricity: C ≤ 1 mm

Control procedures:
- Chemical composition on all tube units
- Mechanical properties on all tube units
- Dimensional control on all the tube units and sections
- Visual control on all tube units
- MPI control on the chamfers
- Ultra-sonic control: 100% of elements for:
  - bodies
  - ends and indicated weld control
- MPI and ultra-sonic inspection of welds.

Manufacturing cycle

For the general manufacture range of a 15 m column. The control procedures are based on:
- Quality Regulations securing the reproducibility of all the manufacturing cycles and the control of the production phases.
- Quality Control not depending on production, that checks the conformity of the products with the Inspection Specifications.

Of the platform each leg is constituted of 4 bracings: 2 of them provided with a rack and 2 without. Half of the 15 m segments were directly forwarded to the Assembly Yard, the other half undergoing several structural modifications. The section of rack bracings gives an idea of the operations that were needed, (a) length cutting of segments and (b) positioning and welding of racks.

(Contd. on page 36)
Centifugally cast steel tubes (Contd. from page 32)

Without going into the details, the construction for which the builder is responsible it should be emphasized that the length of segments was performed in several stages. First, straight cut off at 130°C of 2 elements, by means of 4 cutting nozzles operating together.

After this operation, no important pipe distortion was noticed, the actual pipe diameter varied no more than 1 mm. Then, oxycutting of chambers with a 2 mm root face, the inside rough machining varying according thickness of element, the distance between both root faces of a same half-mould being accurate at a few tenth mm. The last operation consists in chamfer grinding. No crack or fracture ever occurred on centrifugally cast segments during the cutting operations.

The weld consisted in assembling 15 m centrifugally cast half-moulds to sub-units constituted of 2 rack elements and a junction plate. The rack elements were 250 mm wide and 140 mm thick bars in alloyed steel. The first or the two first weld passes were performed manually. Filling was effected in automatic Unionmelt. Both welds have been performed simultaneously on each side of the same rack element.

No particular weld problem appeared on the centrifugally cast half-moulds.

References


Technology (Contd. from page 33)

In conventional units, wear to the drive produces slackness in the coupling so that bar entering the stand does not immediately engage. This reduces the overall efficiency of the rolling process and is also undesirable from the aspect of safety. Also, increased wear is accompanied by greatly increased noise levels.

Over a three-year test period, rolling high strength and exotic materials, wear to the journal of the Farrar Universal Mill Drives was virtually nil and it continued to operate at significantly lower noise levels. Minimal maintenance was necessary and a 95% decrease in grease consumption was reported. Furthermore, the new design has completely removed the need for bronze slippers and consequently the need for regular and costly replacements.

Other advantages include a quick release method for stand changing to reduce downtime and built in length compensation, relaxing the limits on the stand to gearbox installation by means of a collapsible spline. The design also allows for greater angle deflection so that the efficiency of the drive can be maintained on new, reground, or minimal size rolls.

The Farrar Universal Mill Drive can be used as a direct replacement for Morganhammer units, but can also be adapted to other systems. It is available for roughing, intermediate or finishing stands.

Further information can be had from Farrar Precision Engineering Ltd., Diameter Works, Oughtibridge, Sheffield 530 3HN, England.

Technical Services Committee
(Contd. from previous page)

carbon is thus in a combined state and does not separate out as in the case when you take drillings from test bars which has solidified grey. There are several ways of taking such thin samples as follows:

(i) Cast pin samples — may be obtained by pouring molten iron into a specially designed metal mould giving a block of solid iron with several short pins about 3 mm in diameter, projecting from the base of the block. The sample solidifies quickly and pins can be broken from the block in about a minute after pouring. These pins should be immediately placed in a suitable container. The pins are crushed and used for analysis.

(ii) Suction pin samples are obtained by sucking molten metal quickly into a silica or pyrex glass tube of 3.5 mm bore. Suction is provided by a rubber bulb attached to the top end of the tube.

(iii) Rotary sampling — a very thin, broken ribbon sample may be obtained by pouring iron from a spool into a rotary sampling machine. The machine contains a rapidly rotating disc in a nitrogen (O2 free) containing enclosure. Instead of oxygen free nitrogen, helium or argon may be used to produce more rapidly dissolving ribbon free from surface Nitriles. After pouring and solidification instantaneous cover is removed and sample collected and transferred to a suitable container for future analysis.

D. V. Parampie,
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