United States Patent [19]

Hallerberg et al.

[11] **3,863,702**

[45] **Feb. 4, 1975**

[54] **CENTRIFUGAL CASTING METHOD**

[75] Inventors: **William L. Hallerberg; Gilbert W. Gordon,** both of Kokomo, Ind.

[73] Assignee: **Cabot Corporation,** Kokomo, Ind.

[22] Filed: **Jan. 12, 1973**

[21] Appl. No.: **323,104**

[52] **U.S. Cl.** **164/114,** 164/55, 148/30, 148/27, 148/19

[51] **Int. Cl.** **B22d 13/00**

[58] **Field of Search** 164/114, 118, 55

[56] **References Cited**

UNITED STATES PATENTS

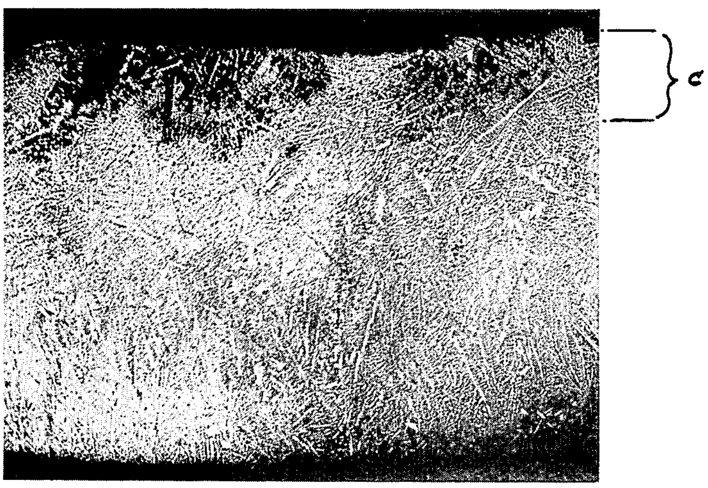
1,831,310	11/1931	Lindemuth	164/114 XR
3,293,708	12/1966	Fruitman	164/114
3,324,933	6/1967	Shewmon	164/114
3,563,300	2/1971	Honda et al.	164/114

Primary Examiner—Andrew R. Juhasz
Assistant Examiner—Rising
Attorney, Agent, or Firm—Buell, Blenko and Ziesenheim

[57] **ABSTRACT**

A method of centrifugally casting hollow metal objects is provided in which molten self-disintegrating slag is added to the rotating mold immediately after casting molten metal and transform in the solid state giving a volume change which causes the slag to disintegrate therein.

7 Claims, 4 Drawing Figures



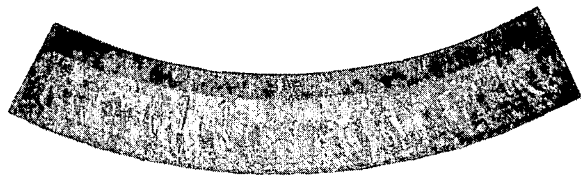


Fig. I.

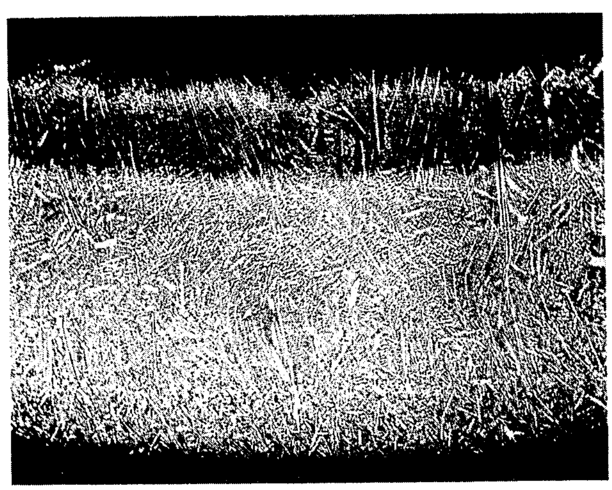


Fig. 2.

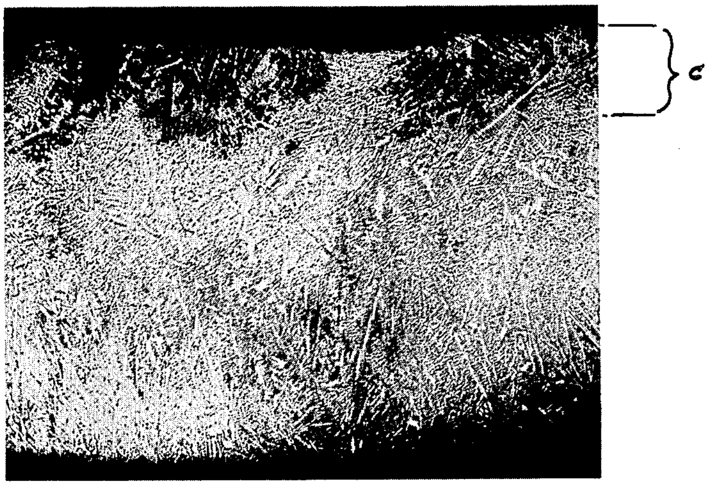


Fig. 3.

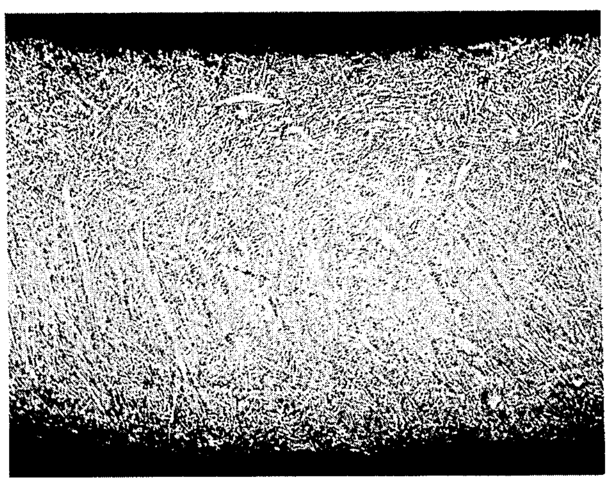


Fig. 4.

CENTRIFUGAL CASTING METHOD

This invention relates to centrifugal casting methods and particularly to a method of centrifugal casting in which a self-disintegrating slag is introduced into the centrifugal mold immediately following the molten metal to form an inner lining in the cast metal. By the term "self-disintegrating slag" we mean a slag which on solid state transformation gives a volume change which causes the slag to disintegrate or break up.

Centrifugal casting of metal into a variety of generally concentric hollow articles such as pipe is well known and has been practiced for many years. It is used in casting gray iron pipe as well as pipe from various types of steels and superalloys depending upon the ultimate use to which the article is to be placed. In the case of steel and superalloy pipe and other hollow articles made of steel or superalloy by centrifugal casting techniques there has long existed a problem caused by shrinkage at the internal diameter of the pipe resulting in porosity and poor internal wall surface smoothness. Such pipe had a high percentage of scrap because of leakage and because of poor surface finish. No satisfactory solution to this problem existed except to cast the pipe to a thicker wall and smaller internal diameter than desired and then to machine out the defective inner wall surfaces down to solid metal to eliminate internal diameter porosity and to provide a good internal surface finish. This is obviously costly both in machine time and labor and in scrap losses.

We have devised a method of overcoming this problem and producing centrifugally cast articles substantially free from internal porosity and with good internal surface. The system is adaptable to any type of centrifugal casting.

We provide a method of centrifugal casting which comprises the steps of introducing molten metal into a rotating centrifugal mold, immediately introducing a molten self-disintegrating slag into the rotating centrifugal mold after the molten metal to form an inner slag lining in the centrifugally cast metal, cooling to cause the metal to solidify and the slag to solidify and disintegrate and removing the slag from the cast metal article. Preferably the slag is introduced into the mold immediately after metal pouring ends, and preferably within five seconds after the metal pour ends. The slag is preferably above about 3,000°F and the slag-to-metal weight ratio is about 0.3 or more. We prefer to use a slag of di-calcium orthosilicate (Ca_2SiO_4) diluted with calcium fluoride to reduce its melting point. Such a slag will decrepitate upon cooling and can be readily removed e.g. poured from the finished cast pipes. Other self-disintegrating slag can be used, if desired; however, we have found di-calcium orthosilicate to be the preferred slag.

In the foregoing general description of our invention we have set out certain objects, purposes and advantages of our invention. Other objects, purposes and advantages will be apparent from a consideration of the following examples and the accompanying drawings which are hereafter described.

EXAMPLE I

A 1,500-pound heat of HAYNES* HL-**40** alloy was cast into ten tubes, 4 ¾-inch OD by ⅜-inch wall thickness by 8 feet long. HL-**40** alloy nominally contains about 30% chromium, about 20% nickel, about 0.40% carbon, up to 2% each manganese and silicon, up to 0.50% molybdenum and the balance iron and incidental elements and impurities. Seven of the tubes were cast using the slag centrifugal invention of adding molten slag immediately after the introduction of a molten metal.

*HAYNES is a registered trademark of Cabot Corporation.

The alloy was poured at 2,850°F into the mold turning at 50 rpm. At the end of the metal pour, the mold speed was increased to 1,150 rpm and then reduced to 900 rpm. One hundred and forty pounds of alloy were used per tube. For the slag tubes, 35 pounds of molten slag were used. Results of the experiment including the time delay between the introduction of the metal and the introduction of the slag, the slag temperature in the furnace, the wall thickness measurements and the depth of shrinkage determined metallographically are shown on Table **1**. Pipes No. **1**, **4** and **9** were made without slag and should be considered standard pipe for this size. The time of slag introduction was measured from the end of the metal pour. The slag temperature was measured in the furnace by optical pyrometer. Wall thickness measurements were made with calipers approximately 3 inches from the end of the tube. Depth of shrinkage was measured metallographically by polishing a cross section of the tube and examining it under the microscope. The numbers indicate the maximum depth of shrinkage found.

TABLE I

RESULTS OF "HAYNES" HL-40 ALLOY, HEAT 2351
SLAG CENTRIFUGAL EXAMPLE I

Pipe No.	Time of Slag Introduction(1), Seconds	Furnace Slag Temperature(2), °F	Wall Thickness Hot End, Inch	Wall Thickness Cold End, Inch	Metallographic Depth of Shrinkage Hot End, Inch	Metallographic Depth of Shrinkage Cold End, Inch
1-1	No slag added	—	See Table II		0.080	0.070
1-2	4.0	2950	⅜	¼	—	—
1-3	5.0	3050	See Table II		0.040	0.055
1-4	No slag added	—	⅜	⅜	—	—
1-5	4.5	3050	⅜	9/32	—	—
1-6	6.5	3050	⅜	5/16	—	—
1-7	8.0	3100	⅜	⅜	—	—
1-8	8.0	3100	See Table II		0.075	0.085
1-9	No slag added	—	⅜	⅜	—	—
1-10	4.5	3150	⅜	9/32	—	—

(1)End of metal pour was t=0
(2)Measured optically in furnace

After cutting off an air test specimen, pipes No. **1, 3** and **8** were sliced lengthwise and the wall thickness was measured with micrometers at one foot intervals along the pipe. The measurements are given in Table II. The acceptable range of wall thickness for this size tube is three-eighths-inch -0 +one-sixteenth or 0.375 to 0.4375 inch.

TABLE II

WALL THICKNESS MEASUREMENTS OF 4¾-INCH OD "HAYNES" HL-40 ALLOY CENTRIFUGALLY CAST PIPE

Position from Cold End Feet	Wall Thickness (inch) Pipe No. 1-1*	Pipe No. 1-3	Pipe No. 1-8
0 (cold end)	0.365	0.377	0.389
1	0.370	0.402	0.393
2	0.375	0.405	0.397
3	0.373	0.403	0.396
4	0.376	0.400	0.385
5	0.380	0.388	0.377
6	0.382	0.375	0.353
7	0.377	0.360	0.343

*Cast without slag

2. Cast two pipes from each heat, 4 ¾ inches O.D. by 0.400-inch wall by 8 feet in length without slag as a standard.
3. Cast 16 pipes, each, 4 ¾-inches O.D. by 0.400-inch wall by 8 feet in length, using the instant slag centrifugal invention.

All pipes had 12 inches cut from the cold end (opposite the pouring spout) and these sections cut in half, with the half away from the cold end sent for air test evaluation. The cold end of each pipe had a one inch thick ring cut from the end away from the cold end. These rings were sectioned into four equal segments and submitted for metallographic examination to determine the shrinkage porosity.

After all pipes were sectioned for the air test evaluation and the metallographic examination, several pipes were sectioned lengthwise for wall thickness checks. Pipe Nos. **2–1, 2—2, 2–4, 2–6, 2–7** and **2–10,** from Heat No. 2,551, were sliced lengthwise and the wall thickness was measured with micrometers at the ends and at one foot intervals along the pipe. Table III shows the measurements along the pipe.

TABLE III

WALL THICKNESS MEASUREMENTS OF 4¾-INCH O.D. HAYNES HL-40 ALLOY CENTRIFUGALLY CAST PIPE FROM HEAT 2551

Position from Cold End, Feet	Wall Thickness (inch) Pipe No. 2-1*	Pipe No. 2-2**	Pipe No. 2-4	Pipe No. 2-6	Pipe No. 2-7	Pipe No. 2-10
1 (Cold End)	0.239	0.406	0.398	0.389	0.365	0.380
2	0.486	0.405	0.392	0.394	0.388	0.387
3	0.565	0.407	0.397	0.402	0.390	0.391
4	0.572	0.418	0.409	0.409	0.406	0.405
5	0.563	0.412	0.404	0.409	0.415	0.410
6	0.348	0.402	0.409	0.411	0.425	0.416
7	0.253	0.402	0.410	0.405	0.434	0.415
8 (Hot End)	0.224	0.386	0.409	0.391	0.434	0.415

Acceptable wall thickness range — 0.375 to 0.4375 inch
*Cast without slag, rotated at 900 rpm.
**Cast without slag, rotated at 1100 rpm.

EXAMPLE II

Two 1,500-pound heats of HAYNES HL-40 alloy were cast into twenty-one tubes, 4 ¾-inches O.D. by ⅜-inch wall thickness by 8-feet long for this experiment. Sixteen pipes were cast using the slag centrifugal technique of adding molten slag after metal pour, and five pipes were cast without the slag addition as a standard.

The normal practice for the centrifugal process is to pour the metal at 2,850°F into a steel mold turning at 50 rpm. After the metal pour, the mold speed was increased to 1,100 rpm and then reduced to 900 rpm until solidification. The first pipe cast in this series was poured per the standard practice, with the exception of the mold speed which was held at 900 rpm. It was found that 900 rpm is too slow because most of the metal stayed in the center of the pipe. The remainder of the pipes were cast following the standard practice with the exception that mold speed was maintained at 1,100 rpm until solidification had taken place.

Slag centrifugal casting procedures used for the series were as follows:

1. Melt self-disintegrating slag and hold at 3200°F or hotter.

The results of the air test can be seen in Table IV. The test pieces were machined to a selected wall thickness and air tested after each wall reduction. The test consisted of sealing each end of the pipe and submerging it in water. Compressed air is introduced at one end of the pipe and is maintained for a specified length of time. The air testing was performed according to Union Carbide Specification, CFTM-100, with the exception of the surface area tested. The specification calls for an inch minimum width, flatbottomed groove to be machined to wall thickness for testing. A three-inch wide, flat-bottomed groove was machined to wall thickness for testing in these experiments because it was believed that the three-inch wide groove would be a more severe test than the one-inch groove due to the greater surface area tested.

The taper of the pipes which were not sectioned lengthwise was obtained by taking five measurements (with micrometers) around the diameter of both the hot and cold ends of the pipe. These measurements were averaged and the difference between the two averages was considered the taper of the pipe and is shown in Table V as wall taper.

TABLE IV

AIR TEST RESULTS (COLD END)
4¾-INCH DIAMETER SLAG CENTRIFUGAL CAST PIPE

Heat No.	Pipe No.	Wall Thickness Range and Failure, (Inch)
2551	2-1*	0.090–0.095**
	2-2*	0.090–0.095
	2-3	0.015–0.020
	2-4	0.015–0.020
	2-5	0.015–0.020
	2-6	0.015–0.020
	2-7	0.030–0.035
	2-8	0.015–0.020
	2-9	0.015–0.020
	2-10	0.030–0.035
2552	2-11*	0.090–0.095
	2-12*	0.130–0.140
	2-13	***
	2-14	***
	2-15	0.015–0.020
	2-16	0.015–0.020
	2-17	0.015–0.020
	2-18*	0.130–0.140
	2-19	0.015–0.020
	2-20	0.015–020

*Cast without slag and should be considered standard production pipe for this size.

**Scrapped.

***Passed 0.020 inch wall thickness; unable to machine further.

The pipe samples submitted for metallographic examination were polished on the fine alumina wheels and then electropolished in a solution of 85 percent methanol and 15 percent sulfuric acid. The results were obtained by measuring at 100X magnification using a table with micrometer type traverse. The numbers indicate the maximum depth of porosity for each sample. The results of the metallographic examination in measuring porosity depth as determined by measurements taken on the polished pipe sections are shown in Table V.

addition. FIG. 1 is a photograph of the polished and etched cross section of the cast pipe showing the condition as indicated by A in the figure. FIG. 2 is a photomacrograph at 8X magnification showing the carbon enriched condition present at the I.D. of the pipe cast using the molten slag as indicated by B in the figure. FIG. 3 is a photomacrograph at 8X magnification showing the shrinkage at the I.D. of the pipe without molten slag as indicated by C in the figure. The amount of shrinkage in pipe cast without molten slag is noticeably greater than that with slag.

Hardness values were obtained on the cross section of several of the cast pipes and disclosed a difference in hardness values of approximately ten points, using the Rockwell A scale, between I.D. and O.D. areas. Due to the amount of hardness difference, samples were submitted for a chemical analysis of the carbon at the I.D. and O.D. Millings were machined from both locations (I.D. and O.D.) of the tube and the results were as follows: I.D. Carbon = 1.20%; O.D. Carbon = 0.41%. Recheck of I.D. and O.D. milling from another tube produced approximately the same results: I.D. Carbon = 1.10%, O.D. Carbon = 0.44%. Carbon specification range for HAYNES **HL-40** alloy is 0.35/0.45; consequently the pipe I.D. experienced a carbon enrichment. Chemical analysis of the heat revealed that all elements, even the carbon, were within the specified range for HAYNES **HL-40** alloy indicating that the high carbon was probably picked up from the slag. It is thus evident that, due to the high temperature and the length of time the molten slag was held in the graphite furnace liner, the slag had picked up carbon from the liner and carbon exchange had taken place between the molten slag and the metal at the I.D. of the pipe.

In order simultaneously to achieve minimum air test shrinkage and minimum pipe wall taper, the results demonstrate the slag temperature must be raised to

TABLE V

RESULTS OF HAYNES HL-40 ALLOY SLAG CENTRIFUGAL EXAMPLE II

Heat No.	Pipe No.	Time of Slag(1) Introduction, Seconds	Ladle Temp.(2) of Slag, °F.	Slag-Metal Ratio	Wall Taper Inch***	Metallograhic Depth of Shrink Cold End, Inch
2551	2-1*	No slag added	—	—	0	0.080
	2-2	No slag added	—	—	0.021	0.120
	2-3	8.0	3000	0.2	0.030	0.020
	2-4	8.0	2920	0.2	0.018	0.040
	2-5	4.0	2800	0.2	0.007	0.030
	2-6	4.0	2820	0.2	0.022	0.040
	2-7	8.0	2820	0.3	0.069	0.025
	2-8	8.0	2820	0.3	0.005	0.025
	2-9	4.0	3000	0.3	0.011	0.035
	2-10	4.5	3000	0.3	0.036	0.035
2552	2-11	No slag added	—	—	0	0.120
	2-12	No slag added	—	—	0.008	0.130
	2-13	8.0	3000	0.3	0.115	0.040
	2-14	8.0	3000	0.3	0.098	0.030
	2-15	8.5	2900	0.2	0.088	0.040
	2-16	8.5	2800	0.2	0.020	0.030
	2-17	5.0	3000	0.2	0.030	0.025
	2-18	No slag added	—	—	0.012	0.100
	2-19	4.5	3000	0.2	0.042	0.030
	2-20	4.5	2820	0.3	0.027	0.040

*Poured at 900 rpm, all others poured at 1100 rpm.

**Difference between hot end and cold end wall thickness of 8-foot tube.

(1) Slag time is after end of metal pour.

(2) Temperature is measured by immersion thermocouple in ladle prior to pour.

Further metallographic studies revealed a dark band around the I.D. of the pipe cast using the molten slag

3,000°F or higher, the slag/metal ratio raised to 0.3 or higher and the slag time cut back to about four seconds or less, and all factors held at these levels with minimum process variation. In addition the "main effect" of heat differences in alloy HL-40 is seen to significantly affect the overall level of pipe taper at the 95 percent confidence level.

Surprisingly, no main effects or interactions were found to be important in controlling metallographic shrinkage which seems to be randomly scattered in magnitude over the entire range of factors investigated. This result may, however, be the result or function of the test method employed. The tubes are cross-sectioned so that one may, or may not, cut into a particular section where porosity is a problem.

EXAMPLE III

Ten pipes were cast eight with molten slag of this invention and two without slag. The practice used was:

1. Melt decrepitating slag to 3,100°–3,150°F maximum. (Although the previous example showed high slag temperatures to be best for taper and shrinkage, temperature was reduced to reduce carbon pickup from the crucible.)
2. Cast two tubes, 4 ¾-inches O.D. by 0.400-inch wall by 8 feet in length, without slag. Mold speed was 50 rpm, for trough, increased to 1,100 rpm until solidification.
3. Cast eight tubes, 4 ¾-inches O.D. by 0.400-inch by 8 feet in length using the instant slag centrifugal invention.
4. Preheat all pouring ladles and tundish as hot as possible. The conditions and operations of the pipe during casting are set out in Table VI.

Specification wall thickness range — 0.375 inch to 0.4375 inch

Metallographic examination of the electropolished pipe cross sections revealed shrinkage depths of 0.035 inch to 0.100 inch. These results were obtained by measuring at 100X magnification using a table with micrometer type traverse and are listed in Table VIII. Also no heavy line was present at the I.D. of any pipe cast in Example III. FIG. 4 is a photomacrograph at 8X magnification showing the absence of the heavy line found in FIG. 2.

TABLE VIII

4¾-INCH DIAMETER SLAG CENTRIFUGAL CAST PIPE METALLOGRAPHIC SHRINKAGE DEPTH MEASUREMENTS

HEAT 2681

Pipe No.	Shrinkage Depth
3-1*	0.100
3-2*	0.100
3-3	0.070
3-4	0.050
3-5	0.040
3-6	0.040
3-7	0.050
3-8	0.060
3-9	0.035
3-10	0.040

Shrinkage measurements are the maximum depth of continuous porosity

*Poured without slag

Hardness values were taken on several pipe cross sections, from the I.D. to the O.D. and disclosed a hardness value difference of from one to two points from I.D. to O.D., the O.D. being slightly harder.

TABLE VI

RESULTS OF HAYNES HL-40 ALLOY HEAT NO. 2681, SLAG CENTRIFUGAL EXAMPLE III

Pipe No.	Time of Slag Introduction, Seconds	Ladle Temp. of Slag °F	Slag Metal Ratio	Metal Temp. °F	Air test, wall thickness range at failure, inch
3-1*	—	—	—	2880	.120–.139
3-2*	—	—	—	2910	.125–.141
3-3	5.1	2820	.3	2850	.026–.038
3-4	3.2	2780	.3	2880	.023–.034
3-5	12.6	2700	.3	2900	.025–.035
3-6	5.9	2850	.3	2900	.030–.038
3-7	5.5	2800	.3	2860	.029–.037
3-8	4.7	2775	.3	2860	.085–.097
3-9	6.2	2790	.3	2870	.030–.033
3-10	6.5	2910	.3	2850	.067–.097

*Cast without slag

Table VII shows the pipe wall thickness measurements at the ends and at 1 foot intervals along Pipe No. 3–9. The measurements are taken on each side of the cut in the pipe from the cold end to the hot end.

TABLE VII

WALL THICKNESS MEASUREMENTS OF 4¾-INCH O.D. PIPE NO. 3-9, HEAT NO. 2681

Position from Cold End, Feet	Wall Thickness, Inch Right Side of Cut	Left Side Of Cut	Average
1	0.383	0.397	0.390
2	0.395	0.404	0.399
3	0.391	0.401	0.396
4	0.398	0.399	0.398
5	0.395	0.399	0.397
6	0.405	0.396	0.400
7	0.403	0.383	0.393
8	0.398	0.378	0.388

Chemical analysis was again taken from the I.D. and O.D. for a carbon check. Results of the I.D. and O.D. carbon check showed little or no carbon difference, both areas being within the specification range.

It will be seen from the foregoing data that the use of molten slag within a centrifugally cast tube will markedly reduce the internal diameter shrinkage depth as well as improve the internal surface of the tube.

While we have illustrated and described certain presently preferred practices and embodiments of our invention in the foregoing specification, it will be understood that this invention may be otherwise embodied within the scope of the following claims.

We claim:

1. The method of centrifugally casting hollow metal objects comprising the steps of:

a. casting molten metal into a rotating centrifugal casting mold,

b. adding a molten self-disintegrating slag which on solid state transformation breaks up to said rotating centrifugal casting mold immediately after casting said molten metal therein,

c. cooling said mold to solidify the metal and cause the slag to solidify and disintegrate, and

d. removing the cast metal object from the mold and the disintegrated slag from the cast object.

2. The method as claimed in claim **1** wherein the self-disintegrating slag is substantially di-calcium ortho-silicate.

3. The method as claimed in claim **1** wherein the self-disintegrating slag is di-calcium ortho-silicate with sufficient flux to provide a desired slag melting point.

4. The method as claimed in claim **1** wherein the self-disintegrating slag is di-calcium ortho-silicate with sufficient calcium fluoride to provide a desired slag melting point.

5. The method as claimed in claim **1** wherein the slag is added within 5 seconds from the termination of pouring of molten metal.

6. The method of centrifugally casting hollow metal objects comprising the steps of:

a. casting molten metal into a rotating centrifugal casting mold,

b. adding a molten self-disintegrating slag containing dissolved carbon to said rotating centrifugal casting mold immediately after casting said molten metal therein,

c. cooling said mold to solidify the metal and cause the slag to solidify and disintegrate, and

d. removing the cast metal object from the mold and the disintegrated slag from the cast object, whereby the internal diameter of the metal is case hardened by the addition of carbon by including dissolved carbon in the slag at the time of addition.

7. The method as claimed in claim **6** wherein the carbon is dissolved in the slag by holding the slag in a carbon crucible at elevated temperature.

* * * * *