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FIRE-CLAY LADLE SLEEVES

By Raymond A. Heindl and George J. Cooke *

ABSTRACT

Eight brands of fire-clay ladle sleeves, representing the product of practically all manufacturers in the United States except those on the Pacific Coast, were tested for service life in a steel foundry and certain properties of these sleeves were determined in the laboratory. The tests made in the laboratory included pyrometric cone equivalent, porosity, Young's modulus, transverse strength, extensibility, and linear thermal expansion.

In coordinating the service results with the results of the laboratory tests, it was evident that much of the trouble experienced in the foundry with the sleeves was due to lack of refractoriness of the sleeves and also to nonuniformity of some of the product, as indicated by the variation in certain of the properties of different specimens of the same brand of sleeves.

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I. INTRODUCTION

Bottom-pouring ladles are equipped with stopper rods to control the flow of metal during casting. These metal stopper rods are pivoted at the top of the ladle and pass vertically through the molten metal to the nozzle at the bottom. To prevent stopper rods from being attacked by the molten metal they are incased in fire-clay sleeves. The number of sleeves required (from 5 to 9) on a rod varies according to the depth of the ladle. The sleeves are joined by fire-clay cement and any space between the rod and the sleeve may or may not be filled with sand, ground firebrick, or similar material.

The manufacture of fire-clay sleeves is limited to a very few plants because the consumption of this specialty is small. However, such sleeves are of great importance since a product which cannot resist

* Mr. Cooke is Quarterman at the U. S. Naval Gun Factory, Washington, D. C.

the thermal shock and also meet the high temperature requirements may mean the loss of the heat or may cause severe injury or loss of life to those engaged in casting the steel.

Recently, difficulties were experienced due to sleeve failures in the steel foundry of the United States Navy Yard in Washington, D. C. As a result of these failures the National Bureau of Standards was requested to cooperate in a study of this fire-clay product. Sample sleeves selected at random from lots purchased by the foundry were studied to determine whether the performance to be expected in service from such sleeves could be evaluated from properties measured in the laboratory.

The problem is of particular interest because it was found possible to correlate results of laboratory tests and actual service results and, as a consequence, to indicate specifications by means of which products of good and poor quality can be readily distinguished on the basis of simple laboratory measurements.

II. SAMPLES AND SPECIMENS

Eight lots of 150 sleeves each were obtained for foundry testing from seven manufacturers or distributors, which represented most of the brands available in the eastern and central parts of the United States. An additional sample furnished on a bid request was tested only in the laboratory. Service data were recorded on approximately 60 of these sleeves selected at random. The sleeves, or hollow cylinders, have a wall thickness of 1¼ inches and are approximately 9 inches long and 5 inches in outside diameter. The ends are shaped to fit into each other, forming a modified taper joint.

For laboratory testing, at least two sleeves were selected in the case of six of the eight brands. The sleeves were cut in half lengthwise, and specimens were cut from the halves for porosity, Young's modulus, transverse strength and thermal expansion tests.

III. LABORATORY TESTS OF MATERIALS

1. CHEMICAL COMPOSITION

In general, the methods described by Finn and Klekotka,[1] and Lundell and Hoffman [2] were followed in making the chemical analyses. The results are given in table 1. The silica ranges from 55.42 to 65.99 percent, the alumina from 25.82 to 38.40 percent, the calcium oxide from 0.14 to 0.30 percent, and the iron, titanium oxides, etc., from 3.39 to 5.27 percent.

TABLE 1.—*Chemical composition (after ignition) of fire-clay sleeves*

Brand	1	2	3	4	5	6	7	8
SiO_2	55.42	58.58	59.62	64.30	65.99	65.48	65.31	65.95
Al_2O_3	38.40	31.77	34.90	27.24	25.82	27.53	26.27	26.76
CaO	0.14	0.21	0.30	0.14	0.26	0.14	0.19	0.17
$Fe_2O_3+TiO_2$, etc.	4.15	5.27	3.85	3.86	3.93	3.39	4.08	3.62

[1] *On a modified method for decomposing aluminous silicates for chemical analysis.* BS J. Research **4**, 809 (1930) RP180.

[2] *Analysis of bauxite and of refractories of high alumina content.* BS J. Research **1**, 91 (1928) RP5.

2. PYROMETRIC CONE EQUIVALENT

The pyrometric cone equivalents (pce or softening points) were determined according to the American Society for Testing Materials[3] standard method, serial designation C24–35. The values given in table 2 range from slightly above 20 to below 33.

3. POROSITY

The porosity determinations were made in accordance with the test method adopted by the American Ceramic Society.[4] The specimens weighed approximately 200 grams and the results of tests are given in table 2.

4. YOUNG'S MODULUS AND STRENGTH

The apparatus for determining Young's modulus of elasticity as well as the transverse strength of the fire-clay sleeves has been described by Heindl and Pendergast.[5] The specimens were tested over an 8-inch span. In general, the same types of curves were obtained as those illustrated in an earlier report.[6]

TABLE 2.—*Pyrometric cone equivalent, porosity, Young's modulus, strength, extensibility, linear thermal expansion, and service classification of fire-clay sleeves.*

Brand [a]	Pyrometric cone equivalent [b]	Porosity	Young's modulus	Transverse strength	Extensibility [c]	Linear thermal expansion: 25 to 1,000° C	Linear thermal expansion: Volume change between, approximately	Service classification [d]
	Cone	*Percent*	1,000 lb/in.²	lb/in.²	*Percent*	*Percent*	°C [e]	
1	32–33 (1,725)	21.8	1,842	1,020	0.553	0.570	100 to 200 small	Very good (8).
2	27 (1,605)	11.4	4,964	1,820	.365	.545	550 to 600 small	Very good (2). Good (2). Fair (2). Poor (1).
2A	29 (1,640)	20.6	3,000	1,520	.506	.545	550 to 600 small	
3	32–33 (1,725)	13.6	3,580	1,850	.515	.670	100 to 200 large	Very good (4). Good (3). Fair (1).
4	23 (1,580)	15.9	3,682	1,775	.486	.620	550 to 600 large	Fair (8).
5	23 (1,580)	20.9	1,898	1,160	.620	.605	550 to 600 large	Fair (8).
6	26 (1,595)	16.1	3,883	1,740	.449	.580	550 to 600 small	Very good (3). Good (1). Fair (1). Poor (3).
7	20–23 (1,555)	14.5	3,120	1,610	.450	.630	550 to 600 large	Very good (1). Good (4). Fair (1). Poor (2).
	27–28 (1,610)	16.9	3,590	2,310	.644	.554	550 to 600 small	
8	23–26 (1,590)	17.0	2,942	1,500	.511	.615	550 to 600 large	Very good (1). Good (2). Fair (2). Poor (3).

[a] Only 1 sleeve available for all laboratory tests of brands 1 and 6, although a refractoriness test was made of a section of a second sleeve of brand 1 and the value obtained was not different from that shown; brands 4 and 5 made by the same manufacturer but marketed as of different quality; brand 7 was received as one shipment but because of differences in appearance two lots of sleeves were tested in the laboratory. For brand 2 the more refractory sample (2A) was received subsequent to the less refractory sample; it was not tested for service life. In comparison with other brands for which more than 1 sleeve was available for test this brand showed by far the greatest range in porosity, namely 9.0 to 20.6 percent.

[b] The numbers in parentheses following the cone numbers are the approximate temperature equivalents in ° C.

[c] Young's modulus divided by the transverse strength.

[d] The numbers in parentheses refer to the number of heats.

[e] Except for the range given, the expansion was fairly uniform between 25 and 1,000° C.

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[3] Am. Soc. Testing Materials, Book of Standards, pt. 2, p. 229 (1936).

[4] J. Am. Ceram. Soc. **11**, 456 (1928).

[5] *Young's modulus of elasticity at several temperatures for some refactories of varying silica content.* J. Research NBS **13**, 851 (1934) RP747.

[6] *Progress report on investigation of fire-clay bricks and clays used in their preparation.* BS J. Research **3**, 691 (1929) RP114.

The modulus of rupture was obtained after completion of the elastic measurements by gradually increasing the load until rupture occurred. The results of the tests are given in table 2.

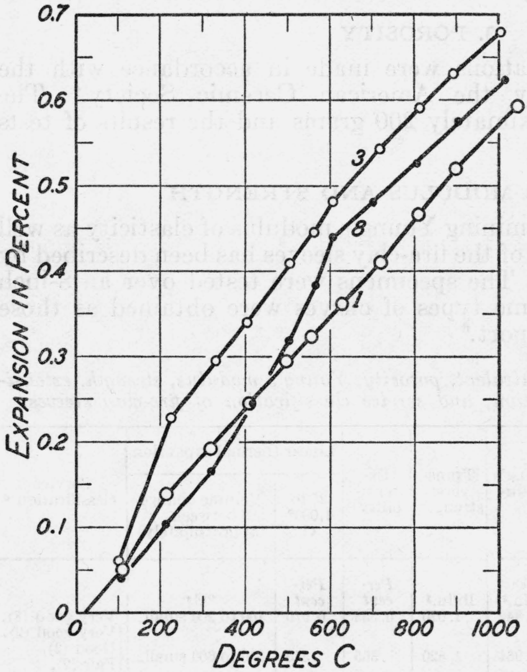

FIGURE 1.—*Linear thermal expansion curves for fire-clay sleeves, brands 1, 3, and 8, showing the three different types obtained.*

5. LINEAR THERMAL EXPANSION

The linear thermal expansion from room temperature to 1,000° C was determined by an indirect method[7] on specimens approximately ⅞ by ⅞ by 6 inches cut from the sleeves. For comparative purposes the total expansion obtained from room temperature to 1,000° C for each brand is given in table 2. It is also noted whether the rate of expansion increased appreciably either below or near 250 and 600° C, owing to crystalline silica inversions. The curves shown in figure 1 illustrate the three types of thermal expansions which were found in tests of the sleeves.

IV. FOUNDRY SERVICE TESTS

1. DESCRIPTION OF SERVICE

In the particular foundry in which the service tests were made, the ladles ranged in capacity from 8 to 30 tons. The average length of time of a pour is about 18 minutes, although on occasion this time may be exceeded by as much as 12 or 15 minutes, depending on the number and size of castings made. Sleeves are never used a second time. As far as type of material is concerned, no differentiation is made between basic or acid steel slags since the same type of fire-clay sleeves are used for either. The temperature of the metal as it leaves the furnace ranges from 1,605 to 1,670° C. The higher temperature is considered desirable to counteract the too rapid chilling of the metal when a great many castings are to be made.

The rod, stopper, and sleeves are dried at a low temperature after assembling. The ladles are preheated by means of an oil burner just before being filled with the molten metal. The temperature, within the ladle and about 6 inches from the wall at a point approximating

[7] J. Am. Ceram. Soc. 9, 555 (1926); BS J. Research 3, 691 (1929) RP114.

the position where the stopper rod would be, was observed to be approximately 675° C just previous to placing the stopper rod in position. The assembled rod, at room temperature, is placed in position immediately after the preheating of the ladle is completed. The ladle is then moved to the furnace and filled with the molten metal. The time interval between the discontinuance of preheating and the flow of the metal probably would not exceed 5 or 6 minutes. The fire-clay sleeves are thus subjected to two thermal shocks; the first, when placed in the heated ladle and the second, when the molten metal is run into the ladle.

In making the foundry tests the several brands of sleeves were subjected to the same service as far as practicable. The majority of the heats were made in an electrically heated basic type furnace. However, the number of heats made in the acid open hearth during the test period was sufficient to give some indication as to the durability of the sleeves used in that type of service.

2. RESULTS

An effort was made to differentiate between the service results obtained when the sleeves were preheated before being placed in the ladle. However, the temperatures of preheating, approximately 40 and 175° C for different assemblies, were apparently too low to have any significant effect on the life of the sleeves.

The results gained from observations made in the foundry are given in table 2. The classification (1) very good; (2) good; (3) fair; and (4) poor, is based entirely on observation of the relative resistance of the sleeves to cracking or spalling and to the cutting action of the slag. Sleeves classed "very good" were those in contact with the metal and slag for the longest periods and which showed very little attack; those classed "good" were in contact with the metal and slag for short periods and which showed only slight attack and no cracking; those classed "fair" showed appreciable cutting by slag, but such cutting while undesirable was not sufficient to cause the loss of the heat; those classed "poor" were badly attacked by slag, cracked or spalled and, in some instances, were the cause of losing the heat.

V. CORRELATION AND DISCUSSION OF RESULTS OF SERVICE TESTS AND PROPERTIES OF MATERIALS AS FOUND BY LABORATORY TESTS

The range in temperature of the metal leaving the furnace, as previously mentioned, is from 1,605 to 1,670° C. During the casting operation the temperature of the metal may drop 50 or 75° C. The point of interest in this connection is that in all but two of the cases given in table 2 the pyrometric cone equivalent (softening point) of the sleeves is below the temperature of the molten steel. The extreme case (brand 7), when the approximate temperature equivalent of the cone and the maximum metal temperature are considered, shows the metal to be hotter by 115° C. On occasion, it has been noted that the lowest sleeve has become bell-shaped by the end of the casting operation owing to deformation caused by the weight of the sleeves resting on it during long exposure at high temperatures. The excessive cutting and pitting shown by some of the sleeves is undoubtedly partially accounted for by the low softening points of those sleeves.

The average porosity of sleeves of the various brands ranges from 11.4 to 21.8 percent. The nonuniformity of sleeves of brand 2 is unusually great since the range in porosity (9.0 to 20.6) in that case is almost as great as the range for all other samples. In some instances this brand of sleeves spalled badly in the foundry and the built-up rod and sleeve assembly could not be used. Spalling and cracking would occur when the warm rod and sleeve assembly was placed in the heated ladle. Pieces remaining from these sleeves were found to have a porosity of 9.2 percent, indicating a porosity as low as that to be undesirable. A high porosity, as in the case of brand 1, does not necessarily mean a low resistance to slag attack; the high refractoriness has apparently an important bearing on such resistance since brand 1 showed excellent resistance to slag in spite of being the most porous.

A low value for Young's modulus in bending and a high value for modulus of rupture would be desirable since it would result in a high extensibility which, as shown in a previous publication,[8] is very desirable from the standpoint of resistance to thermal shock. Table 2 shows brand 2 to range in extensibility from 0.365 to 0.506 percent. The lower value is decidedly lower than the second lowest value. As already stated, brand 2 was the only one which spalled badly when the rod and sleeve assembly was placed in the heated ladle. The low extensibility or "ultimate stretch" of certain sleeves of this brand undoubtedly was a contributing factor to the readiness with which they spalled.

Other properties being equal, it would be expected that sleeves of uniform and low thermal expansion between room temperature and 1,000° C would resist failure due to thermal shock much better than sleeves having a high expansion in either or both of the temperature ranges approximating 150 to 250° C and 550 to 600° C. In the case of fire-clay sagger bodies, the importance of the extent of the expansion between room temperature and 250° C was pointed out by Heindl.[9] In the present case any abrupt change in expansion between 550 and 600° C due to the alpha to beta quartz inversion probably would be equally as important a factor in causing cracking of sleeves as the abrupt change occurring between 150 and 250° C due to the alpha to beta cristobalite inversion, because of the rapidity with which the changes must take place. The inversion at the lower temperature occurs when the rod and sleeve assembly is placed in the hot ladle and the other inversion when the hot steel contacts the sleeves. In table 2 are noted the total expansions up to 1,000° C. It is also noted whether the expansion was greater between the 150 to 250° C and 500 to 600° C ranges than at other temperature ranges between 20 and 1,000° C. In all but two cases (brands 1 and 3) the rate of expansion apparently does not change in the 150 to 250° C range. The rate increased slightly within this range in the case of brand 1 and increased greatly in the case of brand 3. On the other hand, all brands except 1 and 3 showed increased rates of expansion between 500 and 600° C. There is little doubt that the not unfavorable expansion characteristics exhibited by brand 1 contributed to the satisfactory results obtained in service. It is difficult to evaluate the effect of the increased expansion between 500 and 600° C shown by most of the

[8] Raymond A. Heindl. *A study of sagger clays and sagger bodies.* J. Research NBS **15**, 255 (1935) RP827.
[9] *A study of sagger clays and sagger bodies.* J. Research NBS **15**, 255 (1935) RP827.

brands because of the other properties for which values are given and which undoubtedly contribute to unsatisfactory results obtained in service.

Any rating of "poor" in the service-classification column, table 2, indicates that the particular brand of sleeve would be classed as unsatisfactory even though some of the "heats" gave no trouble and are classed "good". This procedure is justified on the basis of the possibility of the partial or complete loss of a heat whenever such sleeves are used. In other words, sleeves should be of such quality that the consumer may have complete confidence in their ability to perform the service expected of them. From table 2 it may be inferred that four of the brands did not give the expected service. The classification ranging from "very good" to "poor" on some brands may be attributed mainly to the nonuniformity of sleeves in the same lot, to the possibility that the sleeves classified as "very good" had the advantage of steel closer to the lower temperature rather than the higher in the range 1,605 to 1,670° C, and also to the possibility that the length of time that the metal was in contact with the sleeves may have been relatively short in certain cases.

In table 2 are given duplicate values for the properties of brands 2 and 7. Differences in these sleeves were so obvious from visual inspection that in the tests they were treated as different types. In both cases, the range in properties from unfavorable to favorable could readily account for the range in service classification from "poor" to "very good".

The chemical composition of the sleeves was determined to learn whether the sleeves highest in silica would be less resistant to attack by basic slag. The data obtained are too meager to warrant drawing definite conclusions, but the results do show that in all cases (approximately 18 percent of total) of acid slag the sleeves gave satisfactory service.

VI. SUMMARY AND CONCLUSIONS

A study was undertaken of eight brands of sleeves made by seven manufacturers. It is believed the product of all manufacturers except those on the Pacific Coast was represented. Certain properties of these sleeves were determined in the laboratory and records were obtained of the behavior of the sleeves in steel foundry service. The results obtained in each of eight heats was recorded for most brands.

The chemical composition, pyrometric cone equivalent, porosity, Young's modulus, strength, extensibility, and linear thermal expansion were determined.

The results obtained in the laboratory are coordinated with the service results obtained in the foundry and the following conclusions appear justified:

1. The temperature of softening of the sleeves in all but two cases was below the temperature of the molten steel surrounding them. In the extreme case the metal was hotter by approximately 115° C.

2. Excessive cutting and pitting during the casting of heats (average time 18 minutes, maximum about 30 minutes) was noted in many of the sleeves of low refractoriness.

3. The average porosity of all brands of sleeves ranged from 11.4 to 21.8 percent, although one brand showed a range in porosity from 9.2 to 20.6 percent for the different sleeves. Those of lowest porosity in this brand gave serious trouble as a result of spalling and cracking.

4. The range in Young's modulus was from 1,842,000 to 4,964,000 lb/in.^{2} The modulus of rupture ranged from 1,020 to 2,310 lb/in.^{2} and the extensibility ranged from 0.365 to 0.644 percent. The highest value for Young's modulus accompanied by the lowest value for extensibility was found in the brand of sleeves which caused much trouble due to spalling and cracking in foundry service.

5. The silica content ranged from 55.42 to 65.99 percent. Service results on the sleeves in contact with acid open hearth slags were satisfactory in all of the limited number of heats observed.

6. The total linear thermal expansions from 25 to 1,000° C ranged from 0.545 to 0.670 percent. All curves showed some inflection due to crystalline silica inversions in either the 100 to 200° C or 500 to 600° C temperature range, although the inflection was small in some cases.

7. The brand of sleeves which gave the most satisfactory results in service was very refractory, had fairly high porosity, a fairly uniform and not high expansivity, and a moderately high extensibility.

8. A great deal of variation in the properties and service results was noted in different sleeves of some of the brands indicating lack of uniformity in the product.

9. There is a sharp dividing line in the degree of refractoriness between the two brands of highest refractoriness and the remainder of the brands. In the purchase of sleeves for the type of steel foundry practice followed by some United States Navy Yards, it would appear desirable to specify a refractoriness requirement. The specified pyrometric cone equivalent expressed in approximate temperature equivalent should be greater than, or at least equivalent to, the maximum temperature of the molten metal as it enters the ladle. It would also seem desirable to specify a porosity requirement of not less than 15 percent. A minimum extensibility value and a linear thermal expansion without erratic changes due to silica inversions are also possible and desirable requirements, but because of the lack of equipment at present in most laboratories for determining the numerical values, it is doubtful that manufacturers could conveniently determine whether their product complied with such requirements. If a refractoriness requirement is specified, not much appears to be gained by specifying limits in the chemical composition.

WASHINGTON, October 28, 1937.