Mining and Metallurgical Section.

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Practical Experiments in Steel.*

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These experiments were undertaken in order to secure for practical purposes a more accurate knowledge of the interior character and structure of the material we are constantly dealing with in the manufacture of what is technically known as boiler plate steel, and used in the construction of boilers, bridges, ships, etc., where the safety of the travelling public is of vital consideration; where I think no one will dispute the statement that we ought to know all that we can learn about the characteristics of the material which enters into this and the safety of the ultimate structure made from it.

Much progress has been made since the first attempt to examine into and specify the character of material to be used in steam boilers, bridges, etc., but through it all I think the records will show the constant effort on the one hand to secure a material of higher tensile strength for carrying higher pressure or heavier loads with, on the other hand, continual vigilance on the part of those upon whom the responsibility of the public safety rests, to require evidences of ductility in the material to avoid the danger point which is approached when the increased tensile strength called for reaches the stage where brittleness results.

My late lamented father, Dr. Charles Huston, took a great interest in the earlier history of these questions and trained up his sons who succeeded him in the manufacture of boiler plate, with a

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strong sense of their responsibility for the elements of safety in the material manufactured and put upon the market.

In the old days of iron, a sample selected from one part of the plate made in the usual manner was as a rule fairly representative of the quality of the material through the remainder of the same plate, the principal element of uncertainty being the question of incomplete welding.

In the early days of the use of steel it was assumed and generally believed that because the metal was all melted together and poured into large ingots to be rolled or otherwise worked into shape, the plates or shapes resulting would be almost, or absolutely, solid and homogeneous in character, but experience has shown that this early conception has not been entirely borne out, and men have found that the material is not absolutely solid, nor entirely uniform in character throughout the mass.

This lack of uniformity has become more noticeable as larger masses have been used, so that a careful investigation into the distribution and degree of this inequality seemed important.

It has been thought by many that the hardening elements were gathered toward the top of the ingot mass by floatation, and that if a good portion of discard was cut from this top end the remainder of the material would be comparatively uniform.

Others have discovered a tendency in hard or medium steels to segregate the hardening elements toward the center or axis of the mass and have concluded, as I also did at first, that this applied to soft steels as well, and that the resultant of this in combination with the floatation tendency was to form a trumpet-shaped hard portion somewhat similar in shape to the inverted "Christmas Tree" observed in a block of manufactured "can" ice.

With this in mind and a desire to examine into the general soundness and structure of some of our standard boiler steel ingots, I had several of them bi-sected vertically, and photographed, with drillings taken from the cut face, and analyses made from representative locations and properly grouped in a chart.

Several of these half ingots resulting from this bi-secting process I had rolled down into plates; also duplicates of the other bi-sected ingots rolled down into plates and cut up to get samples for physical testing purposes with the results appropriately charted, together with further analyses from the corresponding tests; I also show several additional charts to indicate the character and

Photo. 1

Photo. 2

Photo. 3

degree of segregation in ingots of widely differing weights and shapes.

This much for general description and introduction.

Returning to the description of the charts and taking them up by number they may be described as follows:

Photo. 4

Ingots as shown in photos Nos. 1, 2, 3, and 4 were all "bottom" poured at the same time in one group so as to see what, if any difference resulted from difference in shape and weight of ingot mass.

No. 1, 9" x 12" section; No. 2, 16" x 18"; No. 3, 12" x 26",

and No. 4, 8" x 38", all about 36" high, and showing carbon by ladle test .18.

Test charts Nos. 2, 3 and 4 were made from tests of plates rolled from exact duplicates of ingots No. 2, 3, and 4, poured in the same group.

These plates were all rolled about 31 feet long, 76" wide and 5/16" thick. Ingot No. 1 weighed about 900 pounds, while Nos. 2, 3, and 4 weighed about 2850 pounds each, the cross section, while varying decidedly in proportion, figuring up about the same area, and hence resulting in the same weight ingot.

Photo No. 5 was from the sample earlier described (size of ingot, 22" x 15", weight, 3775 pounds) as first bisected; section photographed and then the half ingot rolled into a plate for physical and chemical test as shown in test chart No. 5 (ladle test carbon .23, plate 3/8" thick.)

Test chart No. 6, is from a larger size of ingot (not cut for photograph) and rather higher carbon, being of quality and carbon suitable for what is known as "Marine Steel," used for steamboat boilers, and subject to specifications of United States Board of Supervising Inspectors of Steam Vessels; this ingot was 20" thick by 48" wide, and weighed about 11,000 pounds; the plate was rolled to 29/32" thick.

Test chart No. 7, (ingot not cut for photograph) was rolled from a large ingot 30" thick by 34" wide, weighing about 18,000 pounds, first rolled down and cut into eight slabs 29" wide by 3 1/2" thick, then slabs reheated and rolled into plates 3/8" thick all of one size for physical and chemical test, the location of the slabs as they were cut being carefully noted and traced so as to properly group the tests of the plates in the chart. Ladle test carbon 0.19.

No. 8, photograph shows an ingot cut in a rather different manner, having a quarter section cut out in order to observe the structure of the material in both ways of the section, after photographing.

The other quarter section was cut away and samples taken for chemical analysis, and the remaining bi-sected ingot rolled into a plate for physical test, as shown in test chart No. 8.

Test Chart No. 9, shows carbon determinations from drillings in the ends of the large slabs cut from an ingot of 30" x 50" size, weighing 30,600 pounds, the slabs being 50" wide by 15" thick. Ladle test carbon 0.23, the drillings being taken from the ends of

TEST NO.2

TOP

T.S. 56730 C. .13	67420 .26	67050 .27	66980 .25	56440 T.S. .13 C.
T.S. 56490 C. .13	64930 .22	65100 .23	64620 .23	66140 T.S. .13 C.
T.S. 57000 C. .14	64410 .23	64140 .22	64770 .21	56230 T.S. .14 C.
T.S. 56400 C. .13	63530 .21	62160 .20	62820 .21	56770 T.S. .14 C.

T.S. 56120 C. .13	57720 .13	58400 .16	58140 .16	56940 T.S. .14 C.
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BOTTOM

TEST NO.3

TOP

T.S. 55770 C. .14	63100 .23	65090 .22	64540 .22	56290 T.S. .14 C.
T.S. 55720 C. .13	63080 .21	63290 .21	63160 .22	55070 T.S. .13 C.
T.S. 56530 C. .13	62180 .22	62220 .22	61810 .21	55320 T.S. .13 C.
T.S. 56870 C. .13	60440 .20	60370 .20	60830 .20	55420 T.S. .13 C.

T.S. 54190 C. .13	58660 .17	58430 .18	56630 .18	55130 T.S. .13 C.
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BOTTOM

TEST NO.4

TOP

T.S. 60300 C. .20	64130 .24	64900 .23	63260 .22	61510 T.S. .21 C.
T.S. 57860 C. .15	63820 .22	63210 .23	61960 .22	58540 T.S. .20 C.
T.S. 58670 C. .19	62450 .22	62060 .22	61210 .21	58180 T.S. .19 C.
T.S. 58520 C. .16	60250 .21	61120 .22	59900 .30	56130 T.S. .14 C.

T.S. 55180 C. .14	57630 .17	59210 .18	56100 .18	55740 T.S. .14 C.
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BOTTOM

TEST NO.5
TOP

T.S. 68170	721.60	70840	69700	68270	T.S.
C .30	.33	.38	.35	.38	C
T.S. 67670	70140	69050	68660	68310	T.S.
C .29	.36	.32	.36	.21	C
T.S. 66830	67420	67030	67360	64880	T.S.
C .33	.37	.29	.38	.18	C
T.S. 64130	67680	66830	66730	65230	T.S.
C .23	.37	.29	.38	.16	C
T.S. 65580	65920	65340	64400	65580	T.S.
C .23	.24	.28	.22	.22	C

TEST NO.6
TOP

T.S. 63400	72640	73100	76300	63400	T.S.
C .29	.50	.50	.48	.25	C
T.S. 62700	65500	66900	69750	60500	T.S.
C .24	.38	.35	.34	.23	C
T.S. 63200	66000	66000	65700	60280	T.S.
C .23	.34	.34	.33	.23	C
T.S. 63000	66500	66700	67200	63200	T.S.
C .23	.33	.34	.33	.34	C
T.S. 63400	66500	67100	66000	63000	T.S.
C .22	.29	.30	.39	.23	C
T.S. 63800	66800	66900	64700	65600	T.S.
C .20	.27	.27	.25	.20	C

BOTTOM

BOTTOM

THE IRON AGE

TEST NO. 7

TEST NO.8

TOP

T.S. 66280	62310	62740	61304	66750	T.S.
C .17	.33	.30	.25	.15	C
T.S. 65200	62260	60630	61780	65250	T.S.
C .15	.24	.22	.23	.14	C
T.S. 67340	61790	64670	61070	66250	T.S.
C .15	.22	.20	.21	.14	C
T.S. 66360	65020	67770	66230	66030	T.S.
C .16	.21	.20	.20	.15	C
T.S. 66380	66440	67340	66020	65900	T.S.
C .17	.16	.18	.15	.16	C

BOTTOM

the slabs as cut, so as to represent the central plane of the ingot metal.

These last two charts, Nos. 8 and 9, consequently show the carbon determinations for the central plane of the ingot, while all

the preceding ones show the carbon results from drillings taken entirely through the rolled plate, and hence correspond with the whole thickness of metal which each physical test piece represents, the drillings in each case being located to correspond as nearly as possible with the location of its corresponding sample for physical test.

When the physical and chemical test represent the same metal it will be noted that there is a close correspondence between the results, but when the carbon test represents only the central plane of the ingot as in charts Nos. 8, 9, and 10, the variation in carbon is greater proportionately than the variation in physical properties.

Chart No. 10 is a record of carbons taken across the face of the ingot shown in plate No. 3 and represented by chart No. 3, and made to ascertain where the greatest segregation lay in the line across the transverse axis of the ingot.

It will be seen from these charts showing a wide range of sizes and shapes of ingots that the general character of the segregation is the same.

As the steel cools in the mold a steadily thickening wall of solidified metal forms against the sides of the mold (which is usually of cast-iron) and numbers of gas bubbles form and rise to the surface in the liquid portion, causing a rising current of metal adjacent to the solidified wall with return downward current in the center.

This causes thorough mixing of the portion remaining liquid, but as the carbon and other elements are expelled from the solidifying wall the central liquid portion continually gains in these elements.

This action continues until the temperature of the liquid portion falls to a point where its consistency becomes so thick that the gas bubbles cannot rise through it, when circulation ceases, gas formation ceases and segregation ceases and the metal inside this zone of gas bubbles solidifies in a mass of comparatively uniform character.

The depth from the outside at which these gas bubbles are held may be varied somewhat by the condition and temperature of the metal when poured, but so far as the author of this article knows they have never been entirely eliminated from standard carbon steels.

They may form in a double line with the first one immediately in contact with the mold, resulting in a bad surface in the product, or they may congregate near the center and form large pockets or a pipe, but like the poor, they are "always with us," in some shape, and the disposition of them as indicated in these charts seems to be the best we can make of them so far.

Chart No. 10, shows what might be expected, viz., that the greatest degree of segregation in the transverse axis of the ingot is adjacent to the zone of gas bubbles, the carbon which was last expelled from the solidified metal being held in the adjoining por-

tion of the central mass of metal which was at the time of too thick consistency to circulate and distribute it, the central vertical axis having less carbon than this gas bubble zone except near the top, as indicated by the charts of tensile strength.

It will be manifest from these experiments that the specimens of plate steel available for testing purposes, which as a rule have

to be taken from shearings from the outer margin of the plates as rolled, show the softest part of the metal, and hence there is in the interior much harder metal, in the case at least of very heavy plates, whether rolled directly from the ingot or from the slab, and in any event there is much larger variation in the character of the metal in a large plate than is usually supposed.

This being the case, coupled with the fact that conditions usually require all or part of the test pieces to be cut from the outside softer portions of the plate, brings about a very risky state of things when, in order to carry high pressure, high tensile strength is specified, because it results in the use of material often so hard in its interior portions as to suffer distress in working to shape and reduces the actual factor of safety in the finished structure.

In the earlier rules adopted by the Philadelphia Department of Public Safety in 1882 for iron plates a factor of safety of five was provided for metal of moderate ductility, but where the ductility was high a factor of safety of four was granted, thus encouraging the use of soft, tough metal.

It would be well if some plan could be adopted now and put into general use which would automatically encourage the use of soft ductile metal, thus securing increased safety to the travelling public and doing away with a lot of difficulty and contention between makers and the inspectors who represent the users of the metal; whose rejection of quantities of material often occurs simply because it falls slightly below the required minimum limit, though this material because of its greater ductility can withstand being worked into the required form for the finished boiler with less risk of weakness developing and is more worthy of carrying the required unit stresses under conditions of service than would be a harder metal of the same thickness.

Under present general engineering practice the working stresses allowable are based entirely upon the minimum tensile strength shown, ductility and maximum tensile being introduced only as a check.

It would be far better I believe if the ductility were introduced as a factor in conjunction with tensile strength to determine the allowable working stresses so that a somewhat lower tensile steel may be used, where it shows a corresponding increase in ductility.

In fact I believe it would result in great improvement over

present practice first to determine the maximum unit stress and then specify the range of tensile stress allowable in the steel coupled with a corresponding proper ductility showing; for instance, given a maximum unit stress of 12,000 pounds per square inch for one class of service specify that the steel shall be allowed a range from 50,000 to 60,000 pounds T. S., provided it also shows a ductility of 1,500,000 pounds divided by the actual T. S. in pounds.

This would result in a factor of safety of five with steel of ordinary ductility, but where the ductility showing is high permit a somewhat less factor of safety, and thus encourage the use of soft steels which, judging from experiences of many years, would result in far greater safety to the public service.

The above suggestions are applicable only to material to be used in tension.

For material to be subjected to compression or to bending (which is a combination of tension and compression) or to alternating stresses or to vibration, different rules would have to be worked out, each adapting to the conditions of service; first, study all that can be learned of the material and conditions of service, and then use "horse sense" in adaptation of material and the adoption of rules to secure the needed qualities in material without imposing unnecessarily difficult or impractical conditions upon manufacturers of the materials, and in the rules establish sufficient elasticity to allow the exercise of reasonable discretion on the part of an intelligent and practical inspector.

We should then all get along better together and secure, I believe, better material without the rejection and waste of a lot of good material, as often occurs under present rules and methods.