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STEEL FOR FORGE WELDING

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In this paper the principal factors — method of manufacture, chemical composition, fluxing quality, susceptibility to heat and welding temperature — affecting the welding quality of steel are discussed and the average results of 80 tests made on forge welds of hammer-welded pipe are compared with the original material. In addition it is stated that tests have demonstrated that both steel not over 0.15 per cent carbon and minimum tensile strength of 47,000 lb. per sq. in. and that not over 0.20 per cent carbon and minimum tensile strength of 52,000 lb. per sq. in., are satisfactory for forge welding of pipe lines, penstocks, tank-car work and similar construction but that the former is best adapted for welded parts of boilers and pressure vessels. In conclusion the writer believes that the most important consideration to produce uniformly good results in the forge welding of steel, is suitable material, well-trained operators and adequate facilities for the control of operations.

An appendix is devoted to a presentation of the Tentative Specifications for Steel Plates for Forge Welding of the American Society for Testing Materials as revised in 1921.

THE welding quality of steel, and the strength and reliability of such welds, depend on a number of factors, which include principally: method of manufacture, composition of the metal, susceptibility to heat, fluxing quality, the mechanical appliances for handling and controlling the work, and the skill of the operator. There are so many factors present affecting the results that it is often difficult to determine which of these predominates in any particular case. This paper discusses particularly the characteristics of steel for forge welding, with brief reference to other factors which enter the problem.

MATERIAL AND WORKMANSHIP

2 *Method of Manufacture.* Wrought iron is most easily welded, probably on account of the presence of about one and one-half per cent of easily fusible cinder, which enables the metal to be welded at a comparatively low temperature and protects it from injurious oxidation at high temperature. For this reason wrought

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iron can usually be welded without much difficulty, but on account of the presence of this cinder internal defects such as laminations and blisters are more likely to occur after the metal has been brought up to the welding heat. What we term " soft welding steel " may be made by the bessemer or open-hearth process and should be made especially for this purpose, i. e., it should have, as far as possible, sufficient of the characteristics of wrought iron to readily form a " welding scale " at the lowest possible temperature. Very highly refined open-hearth steels, " ingot iron " or electric steel, are, as a rule, lacking in this respect and so far have not shown as good welding quality as soft welding steel or wrought iron. Possibly these may be improved in this respect, but while these metals possess many advantages for other purposes, they do not at present appear to be so well adapted for forge welding.

3 *Composition.* It is well known that comparatively small quantities of nickel, chromium and silicon interfere seriously with welding. Each of these should be under 0.05 per cent. Carbon has a lesser effect and should preferably be low, certainly under 0.30 per cent for any kind of forge welding. The higher the carbon, the lower the melting and burning point of the steel. By the burning point we mean the temperature at which the grain growth has increased to such a degree as to cause actual disintegration and intergranular oxidation of the metal. Sulphur under 0.05 per cent is not harmful and under certain conditions more may be present without injurious results. Phosphorus up to bessemer limits is beneficial to welding.

4 *Self-Fluxing Quality.* On heating iron or steel above 1500 deg. fahr. an oxide scale is formed. The relation between the fusibility of the oxide scale to the temperature at which the metal " burns " is one of the most important factors determining suitability of the metal for welding. This scale consists usually of the magnetic oxide of iron (${Fe}_3O_4$) with a certain percentage of " sonims "[1] from the iron (MnO, P_2O_5, SiO_2, etc.) which tend to make the scale more fusible. The method of manufacture and composition of the steel have much to do with the formation of a suitable welding scale. The range of temperature between the melting point of the scale and the burning point of the metal is about 100 deg. fahr. in good welding steel and distinguishes this

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[1] Solid non-metallic impurities in steel, H. D. Hibbard, Trans. A. I. M. E., vol. xli, p. 803 (1910).

class of steel probably more than any other property. In fact, it is this self-fluxing quality which makes possible the commercial welding of iron and steel. Artificial fluxes, such as borax, may be used to lower the melting point of the scale in welding small parts but at present fluxes are not practicable to apply satisfactorily when working on large production. The fusion of the scale also affords the operator a definite indication of the welding heat, giving him close control over the operation.

5 *Susceptibility of Metal to Heat.* When normal wrought iron or steel is heated above the upper critical point (about 1750 deg. fahr. for soft steel) the grain grows at a rate depending on the temperature and time of heating. When a certain grain size is reached, a disintegration of the metal occurs with intergranular oxidation and the metal becomes " burnt ". When this occurs, the metal is both red-short and cold-short and useless for most purposes. The actual temperatures at which iron or steel is burned depends as much on the protective character and fusibility of the welding scale as anything else. High-carbon steels are more susceptible to damage of this kind in welding than the same class of steel of lower carbon but the carbon is not the only factor, otherwise we might expect highly refined open-hearth steel or "ingot iron" to weld as easily as charcoal iron.

6 The large granular structure caused by exposure of the metal to welding temperature may be reduced to a fine structure (unless the metal has been excessively overheated) by a certain amount of mechanical forging applied while the metal is cooling or by reheating the metal to about 30 deg. fahr. above the upper critical point, followed by cooling in the air, which with soft steel may be comparatively rapid.

7 *Welding Temperature.* To produce intercrystalline union of two pieces of iron it is necessary that the clean surfaces be brought into close contact with a certain pressure. This is possible even at normal temperature with application of sufficient pressure in the case of soft steel, or may easily be done at a temperature slightly above the fusing point of the scale with comparatively little pressure, or at a lower temperature if the fusion point of the scale is lowered by the use of artificial fluxes, such as borax. So that the most favorable temperature for welding depends on the material and mechanical facilities. The usual temperature at which soft steel is found to weld satisfactorily ranges from 2500 to 2600 deg. fahr.

8 The skill and experience of the operator is, of course, a considerable factor in all welding. However, this is offset in forge welding to some extent by the facilities given him for controlling the heat and the work.

RESULTS OF TESTS

9 A number of tests of forge welds (80 in all) made on two rings cut from the ends of hammer-welded pipe about ½ in. thick, compared with the original material taken from the same pipe, 90 deg. from the weld, gave results which are summarized as follows:

Material Away from Weld — Average transverse tensile test.

Elastic limit, lb. per sq. in.	32150
Ultimate strength, lb. per sq. in.	52790
Elongation in 8 in., per cent	29.7
Reduction, per cent	58.6

Efficiency of Weld — Test pieces machined to uniform thickness.

Average of all tests (80 tests), per cent	92.7
Average at extreme end (40 tests), per cent	90.3
Average 2 in. or more away from end (40 tests), per cent	95.0
Minimum at extreme end, per cent	69.0
Minimum 2 in. or more away from end, per cent	82.3

10 The above steel before welding ranged in tensile strength from about 47,000 to 62,000 lb. per sq. in.— most of it being under 57,000 lb. and under 0.16 per cent carbon.

SPECIFICATIONS

11 This brings us to the question of specifications for steel best suited for forge welding. While skillful operators can undoubtedly make a good job of most steels when the carbon does not exceed that of flange steel,[1] it seems desirable, everything considered, to limit the carbon to about 0.15 per cent for important parts where life and valuable property are at stake and a high efficiency of strength of weld is desired.

12 The present A.S.T.M. specification (A78–21–T) for forge-welding steel (see Appendix) calls for steel of not over 0.18 per cent carbon having a minimum tensile strength of 50,000 lb. per sq. in. A.S.T.M. Sub-Committee II of Committee A-1 now have under

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[1] The term "flange steel" is used in the usual sense, referring to steel of flanging quality ranging between 0.15 and 0.25 carbon, although this quality is not confined to steel of these limits.

consideration substituting for this two grades of steel having the following chemical and physical properties:

	Grade A	Grade B
Chemical Composition		
Carbon, per cent[1]	not over 0.15	not over 0.20
Manganese, per cent	0.35 to 0.60	0.35 to 0.60
Phosphorus, per cent	0.04	0.04
Sulphur, per cent	0.05	0.05
Physical Tests		
Tensile strength, lb. per sq. in.	not under 47000	not under 52000
Yield point, lb. per sq. in.	not under 25000	0.5 tensile strength
Elongation in 8 in., per cent	not under 26	not under 24

[1] For plates over ¾ in. thick, 0.02 additional carbon is permissible.

13 Steel of both grades has been forge-welded and used in large quantities with an assumed weld efficiency of 90 per cent. The tests we have made indicate that this figure is warranted for pipe lines, penstocks, tank-car work and similar construction for which " Grade B " may be used. A somewhat lower efficiency or higher factor of safety should, of course, be used for boilers and Class A unfired pressure vessels for which " Grade A " is best adapted.

BOILER-CODE REQUIREMENTS

14 With respect to steel for forge welding, Part I, Section I, Par. 186 of the Boiler Code requires that:

> The ultimate strength of a joint which has been properly welded by the forging process, shall be taken as 28,500 lb. per sq. in., with steel plates having a range in tensile strength of 47,000 to 55,000 lb. per sq. in. Autogenous welding may be used in boilers in cases where the strain is carried by other construction which conforms to the requirements of the Code and where the safety of the structure is not dependent upon the strength of the weld.

Section III, paragraph L-29 reads:

> The ultimate strength of a joint which has been properly welded by the forging process, shall be taken as 28,500 lb. per sq. in., with steel plates having a range in tensile strength of 45,000 to 55,000 lb. per sq. in. Autogenous welding may be used in boilers in cases where the strain is carried by other construction which conforms to the requirements of the Code and where the safety of the structure is not dependent upon the strength of the weld.

The proposed section on unfired pressure vessels with reference to forge weldings, Pars. 5 and 8, reads:

> The ultimate strength of a joint which has been properly welded by the forge process shall be taken as 65 per cent of the tensile strength of the plate.

This weld efficiency seems rather low for Class A vessels and should be still higher for Class B vessels.

15 In Pars. 2 and 3 of Sections I and III, firebox and flange steel are specified *for all parts* of the boiler. There seems to be a conflict in these specifications between the requirements for steel which may be forge-welded, although apparently the intention is to use a steel of lower carbon for this purpose. This would seem to be in line with the best experience, but inasmuch as flange steel has apparently been successfully used for some time in forge-welded boiler construction· where part of the stress is carried by riveted straps, there would seem to be no reason for not continuing this practice when the weld is so reinforced.

FINISHING

16 After the weld is made, internal strains remain in the metal which should be released by annealing. This may be done by heating the piece uniformly to a red heat (about 1500 deg. fahr.) and allowing to cool in the air. Any objectionable amount of distortion which has occurred in the welding operation should be removed, preferably while the piece is at an annealing heat; otherwise it should be reformed and then annealed. Nothing has been said as to the method of welding, scarfing, preparation of the plate, or fuel to be used, as these vary considerably and good results have been obtained with widely different methods of working. Some operators prefer one form of scarfing, others none at all. Some use roller welding machines, but the majority use power hammers.[1] Good welding has been done with coke fire, producer gas, natural gas and water gas, the last being best adapted for forge-welding on a large scale.

17 To produce uniformly a high weld efficiency, the most important considerations are: suitable material, well-trained operators, and adequate facilities for control of the work.

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[1] Details of mechanical appliances for hammer welding in modern American plants will be found in articles by E. F. Thum in *Chemical & Metallurgical Engineering*, September 21, 1921, October 19, 1921, and November 16, 1921.

APPENDIX

TENTATIVE SPECIFICATIONS FOR STEEL PLATES FOR FORGE WELDING[1]

Serial Designation: A 78-21 T. American Society For Testing Materials.

18 These specifications apply to steel plates for forge welding for car tanks and for similar construction.

I MANUFACTURE

19 The steel shall be made by the open-hearth process.

II CHEMICAL PROPERTIES AND TESTS

20 (*a*) The steel shall conform to the following requiremens as to chemical composition:

Carbon	for plates ¾ in. or under in thickness, per cent	not over 0.18
	for plates over ¾ in. in thickness, per cent	not over 0.20
Manganese, per cent		0.40 — 0.60
Phosphorus, per cent		not over 0.04
Sulphur, per cent		not over 0.05

(*b*) The composition of steel for forge-welding plates should preferably be free from silicon, nickel or chromium. Where these elements are present the maximum quantity of any one shall not exceed 0.05 per cent.

21 An analysis of each melt of steel shall be made by the manufacturer to determine the percentages of carbon, manganese, phosphorus and sulphur. This analysis shall be made from a test ingot taken during the pouring of the melt. The chemical composition thus determined shall be reported to the purchaser or his representative, and shall conform to the requirements specified in section 20.

22 An analysis may be made by the purchaser from a broken tension test specimen representing each melt. The chemical composition thus determined shall conform to the requirements specified in section 20.

III PHYSICAL PROPERTIES AND TESTS

23 (*a*) The material shall conform to the following minimum requirements as to tensile properties:

Tensile strength, lb. per sq. in.	50 000
Yield point, lb. per sq. in.	0.5 tens. str.
Elongation in 8 in., per cent	$\frac{1\,500\,000}{\text{Tens. str.}}$

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[1] Issued, 1919; Revised, 1920, 1921.

(*b*) The yield point shall be determined by the drop of the beam of the testing machine.

24 (*a*) For material over ¾ in. in thickness, a deduction from the percentage of elongation specified in section 23 (*a*) of 0.25 per cent shall be made for each increase of $\frac{1}{32}$ in. of the specified thickness above ¾ in., to a minimum of 20 per cent.

(*b*) For material under $\frac{5}{16}$ in. in thickness, a deduction from the percentage of elongation in 8 in. specified in section 23 (*a*) of 1.25 per cent shall be made for each decrease of $\frac{1}{32}$ in. of the specified thickness below $\frac{5}{16}$ in.

25 The test specimen shall bend cold through 180 deg. flat on itself without cracking on the outside of the bent portion.

26 (*a*) Test specimens shall be prepared for testing from the material in its rolled condition.

(*b*) Test specimens shall be taken longitudinally and, except as specified in paragraph (*c*) shall be of the full thickness of material as rolled. They may be machined to the form and dimension illustrated in complete specification bulletin, or with both edges parallel.

(*c*) Test specimens for plates over 1½ in. in thickness may be machined to a thickness or diameter of at least ¾ in. for a length of at least 9 in.

(*d*) The machined size for rectangular bend-test specimens may have the corners rounded to a radius not over $\frac{1}{16}$ in.

27 (*a*) One tension and one bend test shall be made from each melt; except that if material from one melt differs ⅜ in. or more in thickness, one tension and one bend test shall be made from both the thickest and the thinnest material rolled.

(*b*) If any test specimen shows defective machining or develops flaws, it may be discarded and another specimen substituted.

(*c*) If the percentage of elongation of any tension-test specimen is less than that specified in section 23 (*a*) and any part of the fracture is outside the middle third of the gage length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

IV FINISH

28 The finished material shall be free from injurious defects and shall have a workmanlike finish.

V MARKING

29 The name or brand of the manufacturer and the melt number shall be rolled or stamped on all finished material. The melt number shall be legibly marked, by stamping if practicable, on each test specimen.

VI INSPECTION AND REJECTION

30 The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost,

all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

31 (*a*) Unless otherwise specified, any rejection based on tests made in accordance with section 22 shall be reported within five working days from the receipt of samples.

(*b*) Material which shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

32 Samples tested in accordance with section 22, which represent rejected material, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

DISCUSSION

STANLEY G. CHILD. The writer has written to a large number of welded-tank manufacturers with the view of determining the present actual practice in this industry.

The York Manufacturing Company states: "We have had no difficulty in welding standard steel tank plate, excepting with that which contains segregations or impurities."

The Frick Company states: "We do not favor a specified limitation of carbon content, but would suggest that the standard specification for structural and boiler steel as adopted by the Association of American Steel Manufacturers be made the standard."

The Struthers-Wells Company states: "We have been doing electric welding for seven years and gas welding for thirteen years and have never specified or used any other grades of steel plate than the standard grades of tank and flanged steel as made by the Association of Steel Manufacturers. As a concern doing as much or more welding than any in the United States we see no object in attempting to use a softer grade of steel."

The Baldwin Locomotive Works has welded pressure tanks for the past ten years, using the regular grade of boiler steel, without a single record of failure in service.

The William B. Pollock Company of Youngstown, Ohio, states that it is their practice to weld tank material to manufacturers' specification of steel 55,000 to 65,000 lb. tensile strength and carbon content of 0.15 to 0.25, with very satisfactory results.

The Coatesville Boiler Works state: "We have been welding steel plates of tank, flange and firebox grades for a number of years. The steel is all furnished in accordance with the specifications of the Association of Steel Manufacturers."

Henry Vogt Machine Company, Louisville, Ky., states: "We used flange steel of 55,000 to 65,000 lb. tensile, which has a carbon content of 0.15 to 0.25 and is very satisfactory. We have had no trouble with it whatsoever."

John Wood Mfg. Company of Conshohocken, Pa., states: "We use steel of maximum 0.15 carbon with no required tensile strength."

From the replies received it was evident that a large part of the pressure-tank practice of the present time was based on the use of ordinary grades of boiler and tank steel having a tensile strength of 55,000 to 65,000 lb. and governed by the specifications of the American Society for Testing Materials, the Association of American Steel Manufacturers, or the American Railway Association, which were practically identical and which called for rigid chemical and physical tests.

Some manufacturers were using a softer grade of steel for welded tanks with satisfactory results. This grade was equivalent to the A.S.T.M. specification A-78-21-T.

The writer believes that both of these grades of steel should be permitted for welding practice. While a number of experimental tests have been made to show the superiority of soft steels over the standard grades for welding, the cases are more or less special and are not representative of general tank practice. It is probable, for example, that welds made by the electric resistance autogenous process, without adding additional metal, should be restricted to a soft grade of steel as has been found desirable in the forge welding of steel pipe, which is lap-welded and has no metal added.

THE AUTHOR. The references quoted by Mr. Child are not specific enough in that they do not distinguish between the requirements for fusion welding and forge welding or the use to which the welded vessel is to be put, all of which would seem to be important factors. It is quite likely that a different grade of steel than that used for forge welding will be found best adapted for fusion welding although the carbon limits may be the same.

In reply to a question on the hammer test it may be said that this was developed some eighteen years ago by the National Tube Company in connection with the manufacture of lap-welded steel tubes and has been found to be of considerable service. The actual force of impact is not of so great importance although the force should be somewhat in proportion to the size of the piece tested. In the case of boiler tubes a two-pound hand hammer was used; later on pneumatic and mechanically operated hammers were developed on account of the danger to the operator using the hand hammer. In the case of the large forge-welded pipe no standard has been arrived at. The proposed code for unfired pressure vessels recommends a hammer weighing from 4 to 10 pounds. Any hammer which will send vibrations through a cylinder without denting the metal is sufficient. Such a blow on a vessel under static pressure will often cause fracture although the vessel shows no signs of failure under static pressure, indicating that the vibratory stress is better than a much higher static pressure. In regard to the tensile strength specifications of the present code, these are incomplete and more than the minimum tensile strength should be stated. The 47,000-pound minimum tensile mentioned in one part of the code should be adopted for "Class A" vessels which are welded but other parts of the code should be modified so as to be consistent with this specification.

In regard to the use of flange and firebox steel, it is unfortunate that such grades of steel as usually specified for boiler work happen to be just a little too high in carbon to be best suited for welding. It is, of course, possible to make good and sound welds of such steel with care but the Boiler Code Committee is in search of steels with which there is the least difficulty in welding and it was thought that even though another grade of steel was necessary this was better in order to get the best material for forge welding. There would seem to be sufficient tonnage required to warrant a special grade of weld steel. The minimum limit of 50,000 lb. tensile strength in A.S.T.M. specification A–78–21–T is a compromise between those who want higher tensile strength and those wanting good welding qualities.