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Structural steels for welded structures, as related to the practice of bridge construction in the United States

Baustähle für geschweisste Bauwerke, im Zusammenhang mit dem Brückenbau in den Vereinigten Staaten

Os aços de construção para estruturas soldadas e o seu emprego na construção de pontes nos Estados Unidos

Les aciers de construction pour charpentes soudées et leur utilisation dans la construction des ponts aux Etats Unis

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The historical development of a structural steel for welding in the United States had its beginning in the 1930 decade at the same time that structural welding specifications were being promulgated. The following two decades saw a demand for a more weldable steel that would safely meet the requirements for dynamically loaded structures.

There has been a constant development of structural steels and specifications covering materials, design, and construction. This development has been enhanced by numerous programs of research and the constructive thinking of engineers and scientists in various appurtenant fields.

The basic steels for structural use have been limited, generally speaking, to mild structural carbon steel, structural silicon steel, structural nickel steel, a few high strength special steels, and a low alloy group. While all of these have found wide usage in riveted construction, the preponderance of the structural metal has gone into the mild structural carbon steel type. This steel, developed in 1901 following the era of wrought iron, is a soft or mild carbon steel which, since 1949, has been designated as A7 steel for bridges and buildings by the American Society for Testing Materials. The pertinent elements of this specification are shown in Table I.

The A7 steel has been used in many welded highway bridges and also some railroad bridges. The types of welded new steel structures built in America, are as follows: trusses, arches, frames, beams reinforced with cover plates or for composite design, columns, and girders. The welding of railway bridges has been largely limited to repair of existing structures, although a number of all-welded bridges have been built. The welding of highway bridges began with trusses, as a changeover from riveted work. Beam, plate girder spans, and rigid frames are

TABLE I

A7 Steel

Chemical Requirements

	Ladle Analysis	Check Analysis
Phosphorus, max, %:		
Open-hearth or electric furnace:		
Acid	0.06	0.075
Basic	0.04	0.05
Acid-Bessemer	0.11	0.138
Sulfur, max, % (open-hearth or electric furnace)	0.05	0.063
Copper, when copper steel is specified, min, %	0.20	0.18

Tensile Requirements

	Plates, Shapes, and Bars
Tensile strength, p. s. i.	60,000 to 72,000 (*)
Yield point, min, p. s. i.	33,000
Elongation in 8 in., min., %	21
Elongation in 2 in,. min, %	24

(*) The upper limit of 72,000 p. s. i. may be increased by 3,000 p. s. i. for material over 1 $^1/_2$ inches in thickness.

the types most frequently used today. The Bay shore Freeway structures in the city of San Francisco involve some 26,000 tons of welded steel with 2 $^1/_2$ million linear feet of welding, and make up the largest all-welded bridge project in the United States. The structure is equivalent in length to about 9 $^1/_2$ miles of 2-lane highway.

It should be noted that for A7 steel there is no specified limit for either carbon or manganese, both of which elements are contained in steel. Likewise, a killed steel is not specified for any thickness of plate and this is a further detriment especially for the weldability of thick material. Since such a steel can be subject to hardenability, under-bead cracking, and notch sensitivity, it is obvious that a change in specifications was needed to insure sound work. Although much of the A7 steel being manufactured at the present time has chemical characteristics which assure good weldability, and that the thicker plates are either semi-killed or fully killed, the fact remains that since this specification does not assure definite weldability, there was motivated an effort to obtain a specification acceptable to the American steel industry having the physical properties of A7 steel and chemistry and process of manufacture sufficiently restrictive to assure satisfactory weldability.

It may be well at this point to review the meaning of the term weldability, because we are constantly confronted with the statement that A7 steel is weldable because it has been used in such a large number of structures. The term weldability involves the degree of satisfactory service. The steel that went into a welded ship that failed, or into a bridge that collapsed, was «weldable» in the sense that it was welded with ease. In this sense, structural silicon steel with 0.40 percent carbon is «weldable». However, this is not true of weldability. The American Welding Society's definition for the term «weldability» is as follows:

«The capacity of a metal to be welded under the fabrication conditions imposed, into a specific, suitably designed structure and to perform satisfactorly in the intended service.»

Thus, «weldability» involves the ease with which a material can be welded with due consideration to all variables and to the necessity of obtaining acceptable physical properties and performance. Considering the frequency of cracking of A7 steel during and after welding, it is evident that a more weldable type of structural steel has been needed.

The welding era for structures may be said to have begun in the 1920 decade. For bridges and buildings, the currently existing form of the A7 type of steel was used for both riveting and welding. After the first edition of the American Welding Society's Specifications for Highway and Railway Bridges was published in 1936, efforts were begun to specify a more suitable steel than A7. Numerous attempts before 1950 met with failure on the part of the engineers and the producers to agree.

In 1951, the steel manufacturers consented to furnish the State of California for the Bayshore Freeway structures, a more weldable type of steel. The principal characteristics are shown in Table II.

In 1953, after the steel producers had been approached in the hopes of obtaining a jointly agreeable specification for general use in welding and patterned on the California specification shown in Table II, the following specification was agreed upon for both plates and shapes. This specification has been adopted by the American Welding Society and will appear in the forthcoming edition of their Bridge Specifications, also by the American Society for Testing Materials and published as Tentative Specification for Structural Steel for Welding, A373-54T, and also by the Bridge Commitee of the American Association of State Highway Officials.

The Tentative Specification for Structural Steel for Welding by the American Society for Testing Materials, ASTM Designation: A373-54T include the following requiremens:

1. This specification covers structural material not over 4 inches thick.

2. The steel is made by the basic open hearth or electric furnace process.

TABLE II

Bayshore Freeway Steel

Chemical Requirements (plates only), Ladle Analysis

	THICKNESS		Over 1 in.
	To 1/2 in.	Over 1/2 ins., to 1 in., incl.	
Carbon, max, %	—	0.25	0.25
Manganese, %...	—	0.50 to 0.90	1.15, max.
Phosphorus, max, %...	0.04	0.04	0.04
Sulfur, max, %	0.05	0.05	0.05
Silicon, %	—	—	0.15 to 0.30

Physical Requirements (plates only)

	THICKNESS		Over 1 in.
	To 1/2 in.	Over 1/2 ins., to 1 in., incl.	
Tensile strength p. s. i.	58,000 to 75,000	58,000 to 75,000	58,000 to 75,000
Yield p. s. i.	32,000	32,000	32,000
Elongation in 8 in. min., %	21	21	21
Elongation in 2 in. min., %	—	23	23

For material over 3/4 to 2 1/2 in., inclusive, in thickness, a deduction from the percentage of elongation in 8 in. specified of 0.25 %, shall be made for each increase of 1/32 in. of the specified thickness of 3/4 in. to a minimum of 19 %.

TABLE III

3. *General Requirements (Chemical) A373 Steel*

	Ladle Analysis	Check Analysis
Phosphorus, maximum, %	0.04	0.05
Sulfur, Maximum, %	0.05	0.063
Copper when copper steel is specified, minimum, %	0.20	0.18

TABLE IV

4. *Additional Chemical Requirements for Plates, A373 Steel*

	To 1/2 in., incl., in thickness	
	Ladle Analysis	Check Analysis
Carbon, maximum, per cent	0.26	0.30
Manganese, per cent	—	—
Silicon, per cent...	—	—

TABLE V

5. *Additional Chemical Requirements for Shapes and Bars, A373 Steel*

	Shapes other than Group A (*) and bars to 1 inch, inclusive, in thickness		Shapes in Group A (*) and bars over 1 inch in thickness	
	Ladle Analysis	Check Analysis	Ladle Analysis	Check Analysis
Carbon, maximum, per cent	0.28	0.32	0.28	0.32
Manganese, per cent	—	—	0.50 to 0.90	0.46 to 0.94

(*) Group A comprises the following shapes as described in the Manual of Steel Construction of the American Institute of Steel Constructions

Wide Flange Beams in Nominal Sizes (inches)

36 by 16 ½	30 by 15	21 by 13
36 by 12	30 by 10 ½	14 by 16
33 by 15 ¾	27 by 14	14 by 14 ½
33 by 11 ½	24 by 14	12 by 12
		10 by 10

TABLE VI

6. *Tensile Requirements, A373 Steel*

Plates, Shapes, and Bars

Tensile strength, p. s. i.	58,000 to 75,000
Yield point, min., p. s. i.	32,000
Elongation in 2 in., min. per cent	21
Elongation in 2 in., min. per cent	24

Over 1/2 to 1 in., incl., in thickness		Over 1 to 2 in., incl., in thickness		Over 2 to 4 in., incl., in thickness	
Ladle Analysis	Check Analysis	Ladle Analysis	Check Analysis	Ladle Analysis	Check Analysis
.25	0.29	0.26	0.30	0.27	0.31
.50 to 0.90	0.46 to 0.94	0.50 to 0.90	0.46 to 0.94	0.50 to 0.90	0.46 to 0.94
—	—	0.15 to 0.30	0.13 to 0.33	0.15 to 0.30	0.13 to 0.33

7. *Bending properties*

The bend test specimen shall stand being bent cold through 180 degrees without cracking on the outside of the bent portion to an inside diameter which shall have a relation to the thickness of the specimen as prescribed in Table VII.

TABLE VII

Bend Test Requirements, Plates, Shapes, and Bars, A373 Steel

Thickness of material (inches)	Ratio of Bend — Diameter to Thickness of Specimen
3/4 and under	1/2
Over 3/4 to 1, inclusive	1
Over 1 to 1 ½, inclusive	1½
Over 1 ½ to 2, inclusive	2½
Over 2	3

Pending the results of more exhaustive tests on A373 steel, the following information has been furnished by one of the major steel manufacturers from their test data on steel plates meeting the requirements of the specification.

For 1/2 inch thick plates, the transition temperature at 12 foot-pounds as determined by Charpy Keyhole impact test specimens ranged from an average of –36° F. to –13° F. with a spread of ± 25° F. for each value.

For plates 1/2 inch to 1 inch thick the transition temperature at 15 foot pounds Charpy Keyhole ranged from –32° F. (3/4 inch thick) to –15° F. (5/8 inch thick) with a spread of ± 25° F. for each value.

For plates 1 inch to 1 $^{1}/_{2}$ inches silicon killed, the transition temperature at 15 foot pounds Charpy Keyole ranged from –20° F. to + 50° F. with a spread of ± 25° F. for each value.

Sample mill test reports for the A373 steel show the following typical properties:

TABLE VIII

Typical Properties of A373 Steel

Thickness (inches)	COMPOSITION					Yield Point p. s. i.	Tensile Strength p. s. i.	Elongation 8 in., %
	C	Mn	P	S	Si			
Plates								
To 1/2 ...	.18 to .26	.45 to .61	.011 to .022	.021 to .040	—	34,400 to 41,610	61,010 to 71,336	21.5 to 33.0
1/2 to 1...	.18 to .24	.48 to .83	.008 to 038	.018 to .036	—	33,300 to 41,500	61,680 to 73,780	24.0 to 32.0
1 to 2 ...	.18 to .20	.55 to .78	.009 to .039	.021 to .035	.16 to .23	33,290 to 39,550	63,560 to 70,620	25.0 to 38.0
Over 2 ...	.18 to .23	.60 to .86	.009 to .021	.022 to .030	.20 to .26	34,710 to 39,440	65,440 to 74,500	30.5 to 38.0
Shapes								
5/8 to 1 ...	.20 to .26	.47 to .67	.007 to .015	.020 to .035	—	37,000 to 44,510	60,120 to 69,840	28.2 to 33.7
1 to 1½ ...	.22 to .26	.52 to .76	.010 to .018	.025 to .035	—	36,270 to 42,960	62,000 to 73,260	27.7 to 34.0

It should be realized that these Charpy Keyhole test values show lower transition temperatures than would result from Charpy V- notch tests. They are shown here merely to give some idea as to the characteristics of the steel. Tests on other steels have shown that transition temperatures based on Keyhole tests can be 10° to 40° below those obtained from V-notch tests.

Table IX shows the workmanship requirements applicable to the A373 steel to prevent underbead cracking as will appear in the forthcoming American Welding Society Bridge Specifications. The references to EXX 15 and EXX 16 electrodes concern the low hydrogen types.

TABLE IX

Welding Requirements, A373 Steel

Thickness	Preheat, interpass temperatures, and electrode requirements
Plates to 1 inch thick, inclusive,	None required.
Plates over 1 to 2 inches thick, inclusive,	EXX 15 or EXX 16 electrodes, or 200° F. preheat and interpass temperature. No welding to be done below 10° F.
Plates over 2 to 4 inches thick, inclusive,	100° F. minimum preheat and interpass temperature with EXX 15 or EXX 16 electrodes or 300° F. minimum preheat and interpass temperature.
Bars and shapes with intermediate and light web and flange to 1/2 inch thick, inclusive,	None required.
Bars and shapes with intermediate and light web and flange 1/2 inch to 1 inch thick, inclusive,	100° F. preheat and interpass temperature or EXX 15 or EXX 16 electrodes. No welding to be done below 10° F.
Bars and shapes with heavy web and flange,	EXX 15 or EXX 16 electrodes, or 200° F. preheat and interpass temperature. No welding to be done below 10° F.

In a discussion such as this, it would be remiss not to mention some of the other steels available to the structural engineer faced with a structural welding problem in the United States. Among the best welding steels we have today are those in the Navy's specifications Mil-S-20166, October 3, 1951, for shapes and Mil-S-16113 (ships), April 15, 1951, for plates. The chemical and physical requirements for the HT Grade are shown in Table X for shapes and Table XI for plates.

TABLE X
Mil-S-20166, Shapes

Chemical Composition, Shapes, HT Grade

Carbon, maximum, %	0.18
Manganese, maximum, %	1.30
Phosphorus, maximum, %	0.04
Sulfur, maximum, %	0.05
Silicon, %	0.15-0.35
Copper, maximum, %	0.35
Nickel, maximum, %	0.25
Titanium, minimum, %	0.005
Vanadium, minimum, %	0.02
Chromium, maximum, %	0.15
Molybdenum, maximum, %	0.05

Physical Properties — Shapes, HT Grade

Thickness, inches	Tensile Strength p. s. i.	Yield Point p. s. i. minimum
Under 1/4	90,000	50,000
1/4 to 1/2, inclusive	87,000	48,000
Over 1/2 to 1, inclusive	84,000	45,000
Over 1 to 2, inclusive	84,000	42,000
Over 2	82,000	40,000

TABLE XI
Mil-S-16113 (ships), Plates

Chemical composition, plates — check analysis, HT Grade

Manganese, maximum, %	1.30
Carbon, maximum, %	0.18
Phosphorus, maximum, %	0.040
Sulfur, maximum, %	0.050
Silicon, %	0.15-0.35
Copper, maximum, %	0.35
Nickel, maximum, %	0.25
Vanadium, minimum, %	0.02
Titanium, minimum, %	0.005
Chromium, maximum, %	0.15
Molybdenum, maximum, %	0.05

Mechanical Properties — Plates, HT Grade

Thickness, inches	Ultimate tensile strength, p. s. i.	Yield point, minimum p. s. i.
Under 1/2	92,000	50,000
1/2 to 1-1/2, inclusive	88,000	47,000
Over 1-1/2 to 2, inclusive	86,000	44,000
Over 2	85,000	42,000

A steel with characteristics and weldability similar to A373 steel is available in Grade M of the following Navy Department Specifications:

TABLE XII

Mil-S-20166, dated October 3, 1951, Shapes

Chemical composition percent — shapes, M grade

Carbon 0.31 max.	Manganese 0.75 max.
Phosphorus 0.045 max.	Sulfur 0.055 max.
Silicon 0.25 max.	Copper 0.35 max.
Nickel 0.25 max.	

Physical properties — shapes, M grade

Tensile strength 60,000 p. s. i.
Yield point, minimum p. s. i.

Under 1/4 inch thick	37,000
1/4 to 3/8, inclusive, thick	35,000
Over 3/8 to 5/8, inclusive, thick	34,000
Over 5/8 thick	33,000

TABLE XIII

Mil-S-16113, Ships, dated 15 1951, Plates

Chemical composition percent maximum — plates, M grade

	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper	Nickel
Under 5/8 inch thick... ...	.26	.90	.045	.055	—	.35	.25
5/8 to 3/4 inch thick... ...	.27	.90	.045	.055	—	.35	.25
3/4 to 7/8 inch thick... ...	.28	.90	.045	.055	—	.35	.25
7/8 to 2 inches thick... ...	.28	.60-.90	.045	.055	.15-.30	.35	.25
Over 2 inches thick	.30	.60-.90	.045	.055	.15-.30	.35	.25

Mechanical properties — plates, M grade

	Tensile strength	Yield point, minimum
Under 3/8 inches, excl.	58,000	36,000
3/8 to 5/8 inches, excl.	58,000	34,000
5/8 to 3/4 inches, excl.	58,000	33,000
Over 3/4 inches, excl.	58,000	32,000

It is interesting to note that the new A373 welding steel costs very little more than the long used A7 structural carbon steel. Table XIV shows mill extras, dollars per ton, as of August 6, 1953, for the two steels. The large extra for plates 1 inch to 1 $^1/_2$ inches in thickness for the new A373 steel is due to the fact that it is a silicon killed steel in these thicknesses. The mill extras represent the amounts to be added to the base price for control of chemical requirements.

TABLE XIV

Mill extras, dollars per ton, August 6, 1953

Plates	A7	A373
Up to 1/2 inch	1.00	2.00
Over 1/2 to 1 inch	1.00	4.00
Over 1 to 1-1/2 inches	1.00	14.00
Over 1-1/2 to 3 inches	14.00	17.00
Over 3 to 4 inches	16.00	19.00
Shapes		
Intermediate and light	—	2.00
Heavy	—	4.00

Engineers are forced to give careful consideration to the fact that welding has certain detrimental effects upon steel that are not encountered in riveting. The difficulties must all be recognized, understood and overcome, if welded structures are to be safe for the various types of modern loadings and to safely withstand the conditions to be imposed. It is not within the province of this paper to discuss the various groups of welding difficulties, but it is felt that it is pertinent to the subjct to summarize briefly certain welding effects arising out of the base metal characteristics.

Naturally it is desired to produce a welded structure in which the welded joints remain 100 percent efficient and as nearly unnoticeable as practicable. This requires a minimizing of cracking, warping, residual stresses, and failures at or near welded joints. In turn, these require a minimizing of air hardening, micro-cracks, porosity, notch sensitivity, high transition temperature, high quench effect, and other metallurgical defects. Among other things, these difficulties are affected by chemistry, thickness, and temperature of the base metal, the welding technique, the filler metal, and rigidity of the joint. Brittle fractures are associated with multiaxial stresses, stress concentrations, low temperature, section, size, and rate of loading. Combinations of these factors may reduce ductility to a low value and it is well known that the amount of energy required to propogate a crack through a region of low ductility, is small.

In the welding of steels, a small change in the chemical composition of the base material can seriously affect its weldability. In A7 steel, the principal alloying elements which occur, but which are not explicitly specified, are carbon, manganese, and silicon. These elements may possibly exceed the desired limits for weldability, in which case a transition from a desirable ductile behavior to an undesirable brittle type behavior occurs, the cracking tendency increases and the entire welding procedure becomes complex and may even become impraticable for field conditions.

Ductility decreases rapidly as the carbon content increases above the critical range from 0.20 to 0.25 percent. Below this range, ductility is relatively constant at a high level for say 1/2 inch thickness of material. For thicker material or for conditions involving more rapid cooling, the reduction in ductility occurs at a lower level of carbon content.

Following World War II, the Ship Structure Committee was organized for the purpose of studying welded ship design and construction. These studies have brought to light many fundamental facts concerning the weldability of structural steels. Included in the findings to date are these interesting facts:

(1) Generally, notch sensitivity increased as plate thickness increased.

(2) For a particular strength level, steels with higher manganese to carbon ratios have lower transition temperatures.

(3) The manganese carbon ratio may be a factor contributing to notch sensitivity.

(4) The tear test transition temperature was raised appreciably by increases in carbon, phosphorus, and vanadium content.

(5) Increases in carbon and manganese content, especially carbon, were accompanied by marked increase in crack sensitivity.

(6) For plates of equal thickness, and hence equal metallurgically, the transition temperature rises with the width.

(7) Transition temperature in rolled steel gradually decreases as the extent of deoxidation increases.

The weldability of structural steel decreases rapidly as the carbon content exceeds the range from 0.20 to 0.25 % but the relationship is a complex one and beyond the scope of this discussion. Some of the procedures which tend to improve weldability are increased heat input, preheat, post heat, and proper selection of electrode.

In general, carbon raises, and manganese, lowers, the transition temperature of semikilled steels. The effects of a particular variation in composition differ quantitatively with the criterion used to define notched bar transition temperature. The transition temperature of semikilled steels in notched bar tests may be improved by decreasing the carbon content. Manganese may be used to replace carbon in order to maintain the desired tensile strength. For equal strengths, steels with higher Mn-C ratios have better notched bar properties. Rolling temperatures must be taken into consideration when attempting to evaluate changes and strength and notched bar properties resulting from differences in carbon and manganese contents. The grain size of semikilled steels increased significantly with increases in either carbon or manganese contents.

Transition temperature, at which there is a change from ductile to brittle fracture, is raised by an increase in carbon content. It has been found that increasing the carbon content from 0.12 to 0.25 increases the transition temperature about 90° F. Other elements such as manganese, titanium, vanadium, phosphorus, and silicon may have similar detrimental effects, depending upon the presence and amounts of other elements. The effect of welding is also to increase the transition temperature, so the effect of carbon, for example, may be twofold when the material is welded. Low hydrogen type electrodes help to lower the transition temperature of welds and to control the presence of fish-eyes and porosity.

The cracking sensitivity of steels, as exemplified by underbead and toe cracks, increases with certain alloys, especially carbon. Investigators have noted a sharp rise in the amount of underbead cracking as the carbon content exceeds the critical range from 0.20 to 0.25 percent. Below this range there is practically no cracking. For this reason crack sensitive steel products should not be used in structures subjected to impact and fatigue.

Welding procedures may, to varying degrees, supplant the difficulties encountered from the effects of chemical composition on ductility, transition temperature, and cracking sensitivity. These procedures include preheating, postheaing, increased heat input, special electrodes, and stress relieving.

The weldability of materials having compositions in excess of those mentioned above may be improved by decreasing the cooling rate by either using increased heat input or by the use of preheat. Increasing the heat input is successful only for thin material, say less than 1/2 inch, while for thicker material preheating must be employed.

Similar sensitivity may be caused by the presence of hydrogen, phosphorus, manganese, or silicon, depending upon the presence and amounts of other elements. The A7 steel specification thus does not provide sufficient control over the chemical composition to assure acceptable weldability.

Low alloy steels contain more alloying elements than plain carbon steel and a full discussion of their weldability would be more complicated. The weldability of these steels decreases rapidly as the carbon content exceeds the critical range from 0.15 to 0.20 percent. Hydrogen in these steels becomes more detrimental even at lower carbon contents, because of their high hardenability, so it is often advisable to use a low hydrogen type electrode and perhaps increased heat input, preheating, and postheating.

It is of interest to note some results of laboratory tests made by the Ship Structure Commitee on American Bureau of Shipping steel which is comparable to the A373 structural welding steel.

1. In general, lower finishing temperatures gave lower transition temperatures due primarily to the fine grain resulting from lower finishing heats.

2. Increasing amounts of carbon, phosphorus, and nitrogen increased the transition temperature under all conditions reported.

3. Manganese in increasing quantities decreased the transition temperature under all conditions reported.

4. As silicon is increased in the absence of aluminum, the transition temperature decreases up to about 0.20 percent Si., then increases with further increase in silicon up to a maximum of 0.48 percent Si.

5. Increasing amounts of manganese and nickel lower the transition temperature while increasing amounts of carbon, phosphorus, copper, molybdenum, and silicon increased the transition temperature. The effects of carbon, manganese, and nickel are approximately additive.

Other tests indicate that the transition temperature increases with size of specimen and with widths of plates tested.

The fatigue strength of weld metal from low hydrogen E7016 type electrodes is significantly greater than for the mild E6010 type electrodes, the difference being about 25,000 p. s. i. for preheated welds and 18,000 p. s. i. for quenched welds.

Some high strength heat treated rolled steels for welded structures are being produced in the United States. These steels have been used for pressure vessels and for machinery parts. Yield strength values run as high as 90,000 p. s. i. at the present and values up to 150,000 p. s. i. are proposed. Specifications covering these steels provide for welding crack-sensibility tests for those metal compositions not previously tested. Fillet welds are laid on the thickest material to be used and examined for cracking before and after sectioning the specimens. Only cracks outside the weld metal are considered as cause for rejection of the base metal.

At the present time extensive tests are under way at the University of Illinois to further determine the welding characteristics of the new A373 steel. It is expected that these studies will bring to light much needed information not only on the weldability on the new steel as a base metal but also on various types of welded joints under variable conditions. Considerable information is needed affecting the design and serviceability of welded girders and beam spans.

It may be of interest to quote from an editorial on the new welding steel from «Engineering News Record», dated July 16, 1953, in reference to A373 steel.

«The purpose of the new specification is to minimize the possibility of brittle failures in large welded structures, chiefly bridges. Though brittle failures have occurred in riveted or bolted structures, damage to large welded structures failing in this manner usually is more severe, because cracks can pass through welds and spread over a wide area.

The new specification attempts to prevent brittle failures through requirements for chemical composition. These insure against low notch toughness and segregations in the steel, eliminate «rimmed» steels altogether and make certain that only fully killed steel will be furnished for thick material. Because of the influence of the chemical requirements on the steel mill practices, the weldable steel probably will cost more than A7 steel.

Some engineers may consider the additional cost of the weldable steel a needless expense in view of the satisfactory past record of A7 steel. Also, they may claim that a large portion of A7 steel now being produced could meet the new specification substantially anyway. However, the absence from A7 of requirements for elements other than phosphorus, sulfur, and copper leaves the door open for the production of steel that may not be suitable for certain welded sructures — and it may be noted sometimes not even for some riveting or bolting applications.

The question may well be raised, therefore, as to whether A7 should have been modified to extend protection to all structural steel rather than a new specification introduced. Certainly, a single specification for structural steel that would be applicable regardless of how the material is to be connected is highly desirable, and A7, already in widespread use, could well be adapted for the purpose.»

Thus it appears that after many years of effort, we now have a tolerable specification for a welding structural steel of commercial quality. It must be realized, however, that this new steel specification is not ideal in that the carbon content is still high so that special workmanship is required to insure safe construction when working with the heavier thicknesses. Yet, whatever shortcomings this new specification may have, a great step forward has been made which broadens the horizon for the welding of steel bridges, buildings, and oter structures.

SUMMARY

This paper covers a brief discussion of the development of a welding quality of Structural steel in the United States, from the standard structural steels which have been used for riveted structures. Reasons are developed for the necessity of departing from the common standard structural steel as used for many decades for riveted work. This departure is seen to be fundamental to the field of structural welding.

Experience in the realm of structural welding, combined with a vast amount of welding research growing out of the experience gained during the last war in the welding of ships, has produced for the first time an economical, structural steel for welding which is commercially available for all standard shapes and plates. This steel costs about fifteen hundreths cents per pound or three dollars per ton more than the steel that has been used for riveting for many decades, except that for plates over 1 to 1 $^1/_2$ inches thick the extra cost is thirteen dollars per ton because a killed steel is introduced in this range.

Characteristics of the new welding steel are given, followed by a discussion of both detrimental and desirable features which pertain to an ideal welding quality structural steel.

ZUSAMMENFASSUNG

Der Beitrag enthält eine kurze Besprechung der Entwicklung eines zum Schweissen geeigneten Baustahles in den Vereinigten Staaten, ausgehend von den normalen Baustählen, die für genietete Bauwerke verwendet wurden. Die Gründe sind dargelegt, warum vom normalen, seit Jahrzehnten für genietete Bauwerke verwendeten Stahl unbedingt abzugehen ist. Diese Trennung wird als die Grundlage der geschweissten Bauweise angesehen.

Die Erfahrung im Gebiet des geschweissten Stahlbaues hat gemeinsam mit umfangreichen Schweissuntersuchungen im Zusammenhang mit den Erfahrungen beim Schweissen von Schiffen während des letzten Krieges erstmals zur Herstellung eines wirtschaftlichen, zum Schweissen geeigneten Baustahls geführt, der im Handel in allen normalen Profilen und Platten erhältlich ist. Dieser Stahl kostet ungefähr fünfzehn Hundertstel Cents pro Pfund oder drei Dollar pro Tonne mehr als der jahrzehntelang zum Nieten verwendete Stahl, mit der Ausnahme, dass Platten mit Dicken über 1 bis 1 $^1/_2$ inches dreizehn Dollar pro Tonne Mehrkosten aufweisen, weil in diesem Bereich ein beruhigt vergossener Stahl eingeführt wurde.

Die Merkmale des neuen Schweiss-Stahls sind beschrieben, zusammen mit einer Besprechung der unerwünschten und erwünschten Eigenschaften, die zu einem ideal schweissbaren Baustahl gehören.

RESUMO

Os autores apresentam uma breve discussão acerca da obtenção, nos Estados Unidos, de uma qualidade soldável de aço de construção a partir dos aços de construção correntes utilizados nas estruturas rebitadas. Indicam-se as razões que obrigaram a tomar como ponto de partida o aço de construção de tipo corrente empregado durante muitas dezenas de anos para trabalhos rebitados, facto que foi fundamental no que diz respeito ao emprego da soldadura nas estruturas.

Os ensaios referentes à soldadura de estruturas, aliados a pesquisas resultantes da experiência adquirida durante a última guerra na soldadura de navios, deram ocasião a que se produzisse pela primeira vez um tipo de aço de construção económico aplicável a conjuntos soldados e que se encontra no comércio em todas as dimensões usuais de chapas e perfilados. Este aço custa mais cerca de três dólares por tonelada do que o aço empregado até aqui para construções rebitadas excepto no caso de chapas com mais de 1″ a 1 $^1/_2$″ de espessura em que o suplemento passa para treze dólares por tonelada pelo facto de se empregar um aço acalmado nestas espessuras.

Dão-se as características deste novo aço soldável e discute-se a seguir as características que deverá, ou não, ter um aço soldável de construção de tipo ideal.

RÉSUMÉ

Les auteurs présentent une brève discussion au sujet de l'obtention aux Etats Unis, d'une qualité soudable d'acier de construction à partir

des aciers de construction courants, employés dans les charpentes rivées. L'on y donne les raisons qui ont obligé à prendre comme base l'acier courant de construction employé pendant des décades dans les charpentes rivées, fat qui a été fondamental en ce qui concerne l'emploi ultérieur de la soudure dans les charpentes.

Des essais dans le domaine de la soudure des charpentes, combinés avec d'importantes recherches issues de l'expérience obtenue pendant la dernière guerre dans la soudure des navires, ont rendu possible la production, pour la première fois, d'un acier de construction soudable économique que l'on trouve dans le commerce dans toutes les dimensions courantes de tôles et profilés. Cet acier coûte près de trois dollars par tonne plus cher que l'acier employé jusqu'à maintenant dans les constructions rivées à l'exception des tôles d'épaisseur supérieure à 1″ ou 1 1/2″ pour lesquelles ce suplément est de 13 dollars par tonne à cause de l'emploi d'acier calmé dans ces épaisseurs.

Les auteurs donnent encore les caractéristiques de ce nouvel acier soudable et discutent également les caractéristiques désirables et indésirables d'un acier de construction soudable idéal.

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