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Artikel: The influence of metallurgical factors on the safety of welded structures: stresses and cracking tendency

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The Influence of Metallurgical Factors on the Safety of Welded Structures. (Stresses and Cracking Tendency.)

Zur Frage des metallurgischen Einflusses auf die Sicherheit geschweißter Bauwerke. (Spannungen und Rißneigung.)

L'influence de la composition métallurgique sur la sécurité des ouvrages soudés. (Contraintes et tendance à la fissuration.)

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It may be laid down as a first principle that the reliability of welded structures depends mainly on the design and execution of the welds. In addition, large demands are made on the metallurgist as regards the mechanical properties of the structural steels supplied by him, especially those steels which are heavily stressed, and strict conditions are imposed as to the composition of the latter. Even if the influence of the steel maker on the safety of the structure may appear limited, there is, nevertheless, evidence of a relationship between the chemical composition of the steel and the development of stresses, as well as the tendency to cracking in a welded structure. Here it should be emphasised that such evidence, to be of practical use, can only with difficulty be obtained through laboratory experiments, as the conditions are too complicated. Much has been achieved, however, through practical observation and experience — that is to say, methods which are of real practical use and which throw light on the nature of the steel alloys to be employed — and this knowledge has been won through an intensive and sustained collaboration between metallurgists, welding technicians and designers, continuously and exhaustively applying the results of modern research in all relevant fields.

There is an important consideration which arises in reference to this question, a principle which plays an important part in almost every branch of the application of steel, but which is too often insufficiently observed. The principle is as follows: the higher the grade of the steel — in other words, the greater its utility, and the better it is made — the greater the care with which it must, as a rule, be treated in the later stages. An example is ready to hand: St. 37, which is as simple a material as could be as regards composition and method of manufacture, admits of being worked and heat-treated, etc. within much wider limits than was permissible for St. 48 (a material which has since disappeared from use), even though the latter represented no very great advance over St. 37 in the development of structural steels from the point of view of their stress capacity. From the metallurgical point of view the step to St. 52 was a much greater one, for whereas St. 48 was still purely a carbon steel, St. 52 is alloyed. For this very reason St. 52 must be regarded as a more sensitive material in welding. It follows that in the construction of welded structures using St. 52 the rules of correct welding design and of careful welding workmanship must be even more strictly adhered to than with St. 37.

As regards the metallurgy of St. 52, it is further to be noticed that different compositions and different methods of alloying are practiced in different steelworks, but when comparative experiments are made and differences are discovered in the performance of two kinds of St. 52 these cannot always be attributed to differences in composition or alloying. There can be no doubt that apart from differences in these respects an important part is played by differences in the melting and working procedure which obtains in the different steelworks as a consequence of differences in their equipment and general methods.. These are influences which cannot all be identified in the finished steel.

The experience available in the author's institution regarding the connection between the performance of welded structures and the metallurgy of the steel employed has reference mainly to two kinds of St. 52; one alloyed for the most part only with silicon, the other also with chromium and copper. In the last mentioned, which is the Union-Baustahl, the silicon and manganese contents also, of course, play a part. The experience available in respect of the chrome copper steel is much richer than that with the silicon steel, as the preparation of the latter was very soon found to be exposed to grave defects. For this reason the author's information is based mainly on experience with St. 52 alloyed with copper and chromium.

Moreover, it is perhaps a matter of some importance that this experience has not been derived from a single source concerned only with some particular aspect, but constitutes a summary of experience obtained in the steelworks, the welding workshop and the bridge fabricating shop in collaboration with the Research Institute of Kohle- und Eisenforschung (Vereinigte Stahlwerke).

There are two ways in which the chemical composition of St. 52 would appear to be important as affecting the stress conditions and susceptibility to cracking in welded structures.

It is known that welding gives rise to stresses in the structure which may, in certain circumstances, result in additional stresses difficult to control, and may lead to fractures. The question arises how far the composition of the steel may influence the magnitude of these welding stresses: for it is not reasonable to suppose that notable stresses arise with one kind of steel under certain conditions and none at all with another kind, and the question can, therefore, only be one of difference in the orders of magnitude of the stresses.

An important criterion for the development of these stresses would appear to be the hot yield point of the steel, and this depends in turn on the nature and quantity of the added alloying components. Yet, in another field of work, that of the construction of heavily stressed boilers, it has been found possible to increase the high temperature strength by suitable alloying, to a quite remarkable extent compared with the strength of the ordinary carbon steel. It might have been supposed that as a rule the stresses arising in the welding operation would increase as the hot yield point was increased. Yet careful stress measurements, carried out on the chrome copper steel used by the author, disclosed practically no higher stresses, even under a great variety of experimental conditions, than were found in St. 37, despite the greater high-temperature strength of the former.[1] In one series of experiments, indeed, the stresses in St. 52 were found to be less than those in St. 37: but this result was not found to be generally valid. In no case, however, was a stress found to exist which might be regarded as dangerous by comparison with that in St. 37.

Conditions from the second point of view are somewhat more complicated.

In welding, the zones close to the weld seam are heated to a very high temperature, and if the thickness is considerable the large amount of heat produced in these zones is very rapidly conducted away by the neighbouring cold zones. In other words, an effect may be produced in the highly heated zones which corresponds, or at any rate approximates, to sudden quenching. In this way "hard spots" may be produced in the welded construction, and these hard spots are brittle. It is true they may have a high tensile strength, but under bending stress they tend to crack. Indeed, the hard spots may by themselves lead to cracking, on account of the volume changes which attend the transformations even without the presence of any external load.

The hardening capacity of St. 52 would appear to depend in the first place on its *carbon content.* In accordance with the relevant regulations of the German Reichsbahn the carbon content in St. 52 is limited to 0.20 % for thicknesses up to 18 mm and to a maximum of 0.25 % for still greater thicknesses, this being done in direct reference to weldability. There might be other inducements to the metallurgist to increase the carbon content, especially since strict compliance with the limits imposed thereon makes it difficult to obtain the prescribed yield point (minimum 36 or 35 kg/mm^2). All our experience, however, is to the effect that with due regard to the safety of welded constructions the limit 0.20 % of carbon should not be exceeded. As early as 1933 *Buchholtz* and the author showed that the hardening capacity of the parent material, and especially its carbon content, has much influence on the fatigue resistance of welded St. 52.[2] Thus welded connections made with St. 52 containing 0.24 % of carbon were 20 to 30 % less strong than those made of St. 52 showing the same mechanical strength but containing 0.16 % of carbon. We established the fact that it is desirable, where possible, that the carbon content should not be allowed to exceed 0.18 %. It should be clear, however, that a limit on the carbon content — and still more, as will be explained below, on the other alloy constituents — is to some extent bound to be detrimental to the yield point.

The part played by the other alloy constituents in St. 52, from the point of view of weldability, is more difficult to ascertain, and the conditions in regard to *silicon* appear particularly complex. Silicon in itself does not tend to any great extent towards an increase in hardening capacity, but the dislike of most steelworks for a pure or only slightly altered silicon steel is due to other reasons.

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[1] *H. Bühler* and *W. Lohmann:* Elektroschweißung 5 (1934), p. 226.

[2] Stahl und Eisen 53 (1933), p. 545/52.

In spite of this, the silicon content has for some time been limited to a maximum of 0,4 %, and the author would wish particularly to emphasise that this is so despite the preparation of a large number of meltings with a higher silicon content, approximately 0.6 %. It was quite obvious, however, that the steelworks experienced difficulties with this high silicon steel, with the result that the limit of 0,4 % is now strictly adhered to.

The maximum content of *manganese* which we allow is 1.1 %. According to the experience of some other works 1.5 % is permissible, but doubtless only with a correspondingly smaller content of other alloy constituents. In this connection it may be mentioned that according to *Sandelowski*,[3] and also according to *Schulz* and *Püngel*,[4] electrodes with a high manganese content tend to a greater amount of shrinkage in the seam and greater stress in welding.

Copper is added to the Union-Baustahl up to 0.8 %, without any difficulties or disadvantages from the point of view of the safety of welded connections being disclosed. In this connection it is of interest to note a recent publication by *S. Epstein, I. H. Nead* and *I. W. Hally*,[5] who, in attempting to develop a weldable steel with a good strength at high temperatures, arrived at the following composition:

	C	Si	Mn	Cu	Ni	P
Maximum:	0.10	0.15	0.50	1.00	0.5	0.12

Here the limit of carbon content is very much reduced. The manganese and the silicon are also kept low, while a copper content of 1 % is regarded as advantageous. The high content of phosphorus is also of interest from this point of view.

The presence of *chromium*, when it exceeds certain limits, gives rise to undesirable effects in welding, and chromium also tends to hardening. Regarding this matter of the influence of the chromium content we are in possession of very extensive observations, and from these the rule has been laid down that the chromium content should not be allowed to exceed 0.4 %. Up to this limit, the presence of chromium has not given rise to any difficulties. In other works a higher limit is allowed, and mention may be made particularly of the British Chromador steel, wherein, to the author's knowledge, the chromium content is as much as 0.8 %. It would be of interest to learn what experience has been obtained in the welding of this steel.

Molybdenum, within the limits that it is present in St. 52, may doubtless be ignored from the point of view of the quality of welds.

In reproducing the chemical composition proposed by *Epstein* and his collaborators special attention was drawn to the phosphorus content, which reaches the high value, according to our ideas, of 0.12 %. We now know, on the basis of work carried out in our own company, that very often the phosphorus content of steel is not attended by the grave disadvantages which are frequently ascribed

[3] Elektroschweißung 2 (1931), p. 48/53.

[4] Stahl und Eisen 53 (1933), p. 1233/36.

[5] American Institute of Mining & Metallurgical Engineers, 1936, Technical Publication No. 697; Metals Technology, 1936, Vol. 3, April.

to it, but that on the contrary, under certain conditions, it may be regarded as a useful and desirable element. For our steel St. 52, the author would not indeed regard so high a phosphorous content as in the American steel as desirable[6]: but to say this is not to imply anything against the American steel, for it would appear that the danger from phosphorus decreases in proportion to the carbon content, and in the American steel the latter is very low. It would be of great interest to learn more about the behaviour of this American steel in welding.

In the German St. 52 the phosphorus content is manifestly so low, since it is a basic Siemens-Martin steel, that as regards the performance in welding and on the site no difficulties can arise through its presence. The same is true in regard to the sulphur content.

Addendum.

While the report was in the press, regulations were issued by the German Reichsbahn allowing increased amounts of alloy in St. 52, the main object of this being to obtain a better guarantee of weldability while at the same time approximating the various kinds of St. 52 more closely to one another as regards composition. In accordance with these regulations the following upper limits are laid down for the alloy constituents:

Carbon	maximum 0.20 %
Manganese	maximum 1.20 %
Silicon	maximum 0.50 %
Copper	maximum 0.55 %.

In addition to these constituents the St. 52 may receive a further addition of either chromium up to a maximum of 0.40 % or of molybdenum up to 0.20 %. Finally, an additional manganese content of 0.30 % may be present, bringing the total content of manganese up to 1.50 %, but only in the absence of either chromium and molybdenum.

At the same time, however, the prescribed minimum yield points in respect of the greater thicknesses were stepped down.

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[6] *K. Daeves, A. Ristow* and *E. H. Schulz:* Stahl und Eisen 56 (1936), p. 889/99 and 921/27.