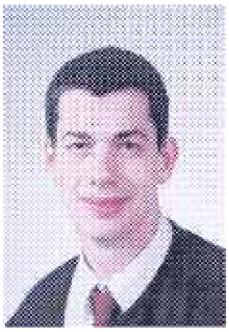
Current world-wide trends in the usage of modern steel plates for bridge constructions



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Summary

It is clear, that constructional steel is the most important input material for steel and composite bridges attaining a value share of up to 40 % on a steel superstructure in dependence of the span length. Therefore it is obvious, that the improvement of the efficiency of steel products in design, fabrication and service life of a steel structure is a key element to develop also the efficiency of the bridge.

This articles focuses on such new developments in the steel producing industry for use in steel bridge construction. Therefore, not only the European approach will be discussed. Furthermore, also the recent developments for the production of steel plates in the US and in Japan will be highlighted.

In particular the opportunity of producing higher strength plates will be described. Today such plates are produced by the thermomecanically rolling process and the quenching and tempering process. Examples for the application of such grades in bridgebuilding will be given. Furthermore, the concept of weathering steel in order to obtain a cost reduction through the entire life of a bridge by avoiding cost-extensive coating will be discussed. These grades are today very popular in the US and in Japan, however still not so often used in Europe.

Keywords

Steel, TM-process, high-strength steel, weather-resistant steel, welding, longitudinally profiled plates

1. Introduction

Since the first application of steel in steel structures in the 19th century the development of steel construction has been closely linked to the development in material properties and production methods. Significant achievements concerning strength, economy, design versatility, fabrication and erection techniques and service performance would not have been possible without the substantial improvements of steel, especially by the application of "new" production processes for carbon steel grades with improved characteristics (strength, fabrication properties, durability and so on and so forth). Today, the application of these grades is driven by the following major reasons, for which examples are given:

Economy: By increasing the strength of steel, the structural section can be reduced in dependence of the structural problem. This may reduce fabrication and erection cost - an important task in high-wage economies. On the other hand by application of weather-resistant steel grades the life cycle costs of steel structures can be reduced.

Architecture: The size of structural elements can be reduced by higher strength grades enabling special aesthetic and elegant construction which embed in the environment in an outstanding manner.

Environment: Construction with less steel by use of efficient steel products means also a more efficient input of our world's rare resources. Also the avoiding of a corrosion-protective paint by the use of weathering steel results obviously in environmental benefits.

Safety: Modern steel grades show not only high strength values. Special grades combine this strength with an excellent toughness so that a high safety both in fabrication and application of the structures is applied. In particular modern offshore steel grades performing at lowest service temperature are a good example.

This paper focuses on the recent developments made by the steel industry for offering "tailor-made" steel products for the application in bridges. In the following, the main developments high-strength steel, weather-resistant steel and efficient dimensions will be described.

2. Dimension of steel products

2.1 Dimensional range of available products

In Western Europe steel fabricators are facing the fact that - in long term - wages are increasing by a quicker rate than the raw material, the steel, whose price may significantly fluctuate in short and medium term, however does not show any increase in long terms. Therefore, it is advisable to use plate products by which the efforts for fabrication (in particular welding) can be reduced.

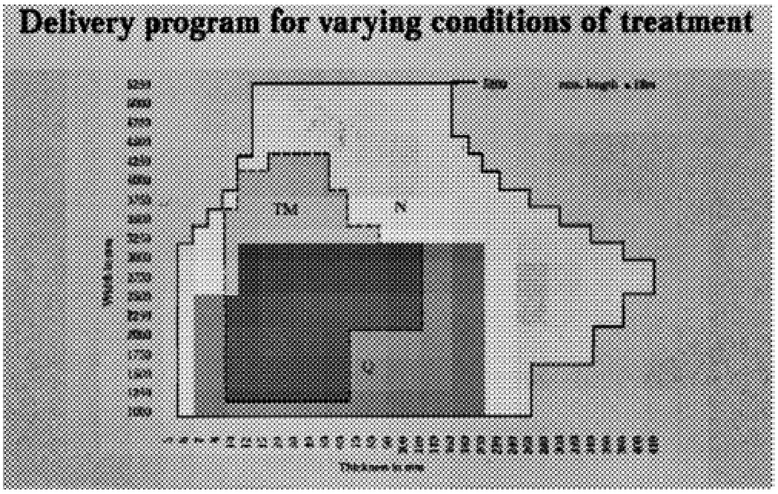


Fig. 1 Deliverable dimensions for heavy plates

Figure 1 shows the deliverable dimensions from European plate mills. By the use of extra-wide and extra-long plates additional butt welds in longitudinal or transverse direction can be reduced and fabrication cost be saved. For instance, Figure 2 shows the new high-speed train bridge across the Hollandsch Diep between Brussels and Amsterdam, in which plates up to a width of 4550 mm have been applied in order to reduce the number of weldings. Of course, this not only results in a more efficient and quicker fabrication but also in reduced sensitivity against fatigue.

Fig. 2 High-speed railroad bridge Hollansch Diep

Whereas the production of extra-wide and extra-long plates only shows a secondary influence on the mechanical characteristics of the steel products, these values may be quite significantly influenced by the thickness of the plates. On the other hand, construction with thicker plates also demands for superior steel grades showing good toughness values in order to avoid the phenomena of brittle fracture. For instance, the coming European construction code EN 1993-1-10 - Selection of material for fracture toughness and through-thickness properties - defines a maximum allowable plate thickness of 65 mm for a conventional S355J2G3 (that means minimum yield stress of 355 MPa and Charpy-V-test of minimum 27 J at -20°C) if a reference temperature of -20 °C and a medium load are applied [1]. For the application of thicker constructional elements a higher grade with improved toughness has to be chosen, for instance an S355NL (that means minimum yield stress of 355 MPa and Charpy-V-test of minimum 27 J at -50°C). This grade is usually also required in French bridges for thickness' above 80 mm.

Due to the lack of steel products with sufficient toughness properties even in greater thickness' in most countries the usage of thicker plates, in particular for flanges, was avoided. Instead, thick flanges were designed by the use of additional, reinforcing lamellae on the top of a basis lamella.

However, steel industry has today succeeded in producing even thick plates with excellent toughness properties due to

- modern steel plant technology (vacuum degassing, argon stirring etc.) to reduce residual elements such as sulphur and phosphorus and minimise the number of non-metallic inclusion.
- availability of slabs and ingots with large thickness as the deformation factor, the ratio between initial slab thickness and final thickness of the plate strongly, correlates to toughness and through-thickness properties.

modern rolling technology, for instance the HS-rolling (High Shape Factor Rolling) characterised by strong deformation ratios during the first rolling passes to improve the core properties of the product, see Figure 3.

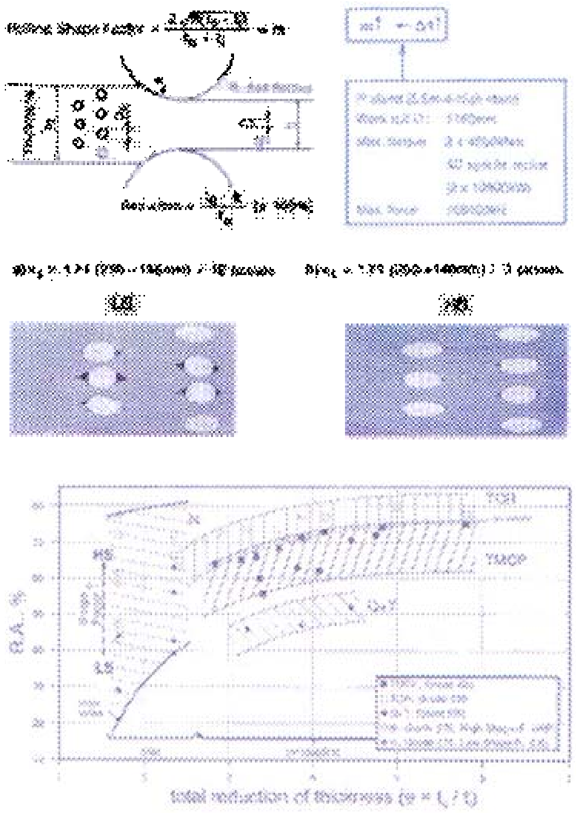


Fig. 3 Influence of High Shape Factor Rolling

Therefore, steel plates with sufficient toughness properties to resist against brittle fracture can be obtained today. For instance Figure 4 illustrates toughness values of plates above 80 mm thickness. It can be seen, that even in extreme thickness' excellent toughness values can be obtained.

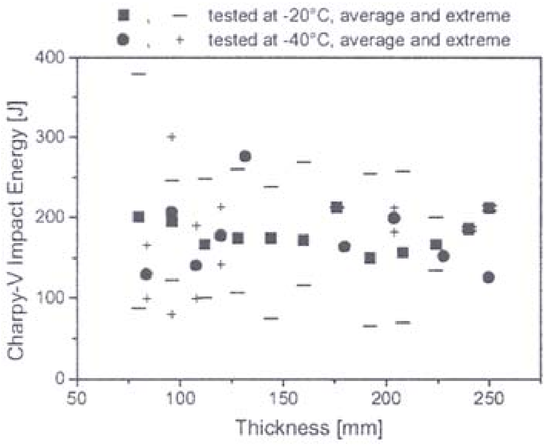


Fig. 4 Charpy V-results of S355 steel for thicker thickness'

Thus, steel bridge constrcution can profit from this opportunity by avoiding the classical "multiple-lamallae-type" flange constrcution and applying thick plates in order to simplify the fabrication process. This tendency does not only exist in Europe as for instance for the typical French twin girder type bridges also used for high-speed train bridges [2] given in Figure 5. Also in Japan and the Northern America this trend of using ultra-thick plates is reported.

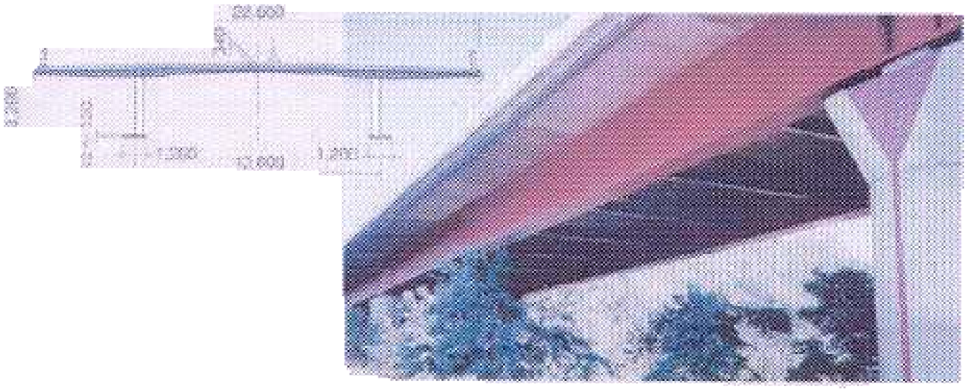


Fig. 5 Thick plates in a French bridge

However, these thick plates are not only useful for the construction of flanges. By the application of heavy plates with a thickness up to 250 mm short span bridges with a span up to 10 m can be erected in a very efficient way. Replacing existing bridge decks on retained abutements by these ultra-thick plates results in erection times of not more than 8 hours as shown on some examples in Switzerland for little railroad bridges. On of these examples is shown in Figure 6. Of course, the fatigue strength of these plates has been approved successfully prior to the construction of this type of bridge.

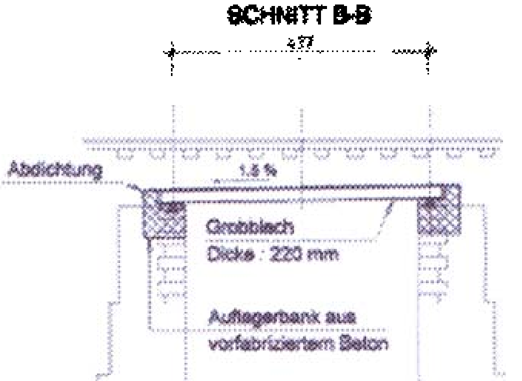


Fig. 6 Ultra-thick plates for short-span railroad bridges in Switzerland

2.2 Longitudinally profiled plates

The demand to reduce weight, i.e. the reduction of the dead weight of the structure and the reduction of the total volume of steel required, was the starting point for the development of the longitudinally profiled plates (LP-plates) [4]. By a special control of the rolling gaps during the rolling process a longitudinal profile with a continuously varying thickness along the length of the plate can be given to a heavy plate. Thus, various types of LP-plates with different geometry's can be produced up to a maximum thickness difference of 55 mm an a maximum slope of 8 mm/m. Such plates allow an optimised adaptation of the plate thickness to the actual stress in the structure. Today, LP-plates are applied in bridgebuilding all over Europe and also in Japan and Korea. Besides reducing the weight, the application of LP-plates saves also fabrication costs and time due to the possibility of avoiding complicated weldings, see Figure 7.

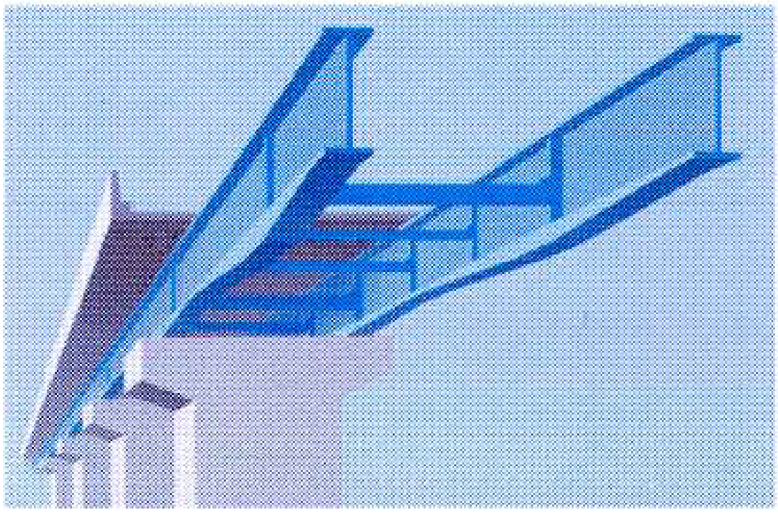


Fig. 7 Principal benefit of LP-plates

Figure 8 shows a recent example, where LP-plates have been applied: In the Schengen bridge at the German-Luxembourg border across river Mosel about 1200 t of LP-plates have been used with a maximum thickness of 150 mm. An example for the application of these special plates in the upper flange is also given.

Fig. 8 LP-plates in the upper flange of the Schengen bridge

3. High strength grades

3.1 Development and production

The development of new steel grades was always driven by the demand of the users wishing for materials showing good mechanical characteristics such as yield strength and toughness as well as excellent fabrication properties ensuring an efficient fabrication technology in the workshop and during the erection of a steel structure. Among others there are two major ways of increasing the yield strength of steel [5-7]:

- Alloying: By alloying elements such as carbon and manganese the strength of steel products can be "easily" increased. But it is known that an addition of alloying elements in most cases also worsens the fabrication properties of steel products in particular the weldability.

- Heat treatment: Heat treatment has an effect on microstructure and grain size. The main advantage of this process consists in the achievement of a fine-grained structure resulting in a higher strength as well as a better toughness of the material compared to a coarse grained (Relation of Hall-Petch).

For this reason the heat treatment is of major importance in the development of new steel grades and the historical context is shown in Figure 9. Until 1950 the steel which is today known as S355J2 was regarded as high tensile steel. As a plate this grade is usually produced by conventional hot rolling (see Figure 10, process A) followed by a normalising heat treatment - a heating slightly above the A_{c3}-temperature (temperature where the ferritic-perlitic structure has totally changed to austenite) followed by a calm cooling resulting in a fine and homogeneous grain structure (see Figure 10, process B). This process can be replaced by a normalising rolling where - simply expressed - this heat treatment is included in the rolling but leads to a similar result.

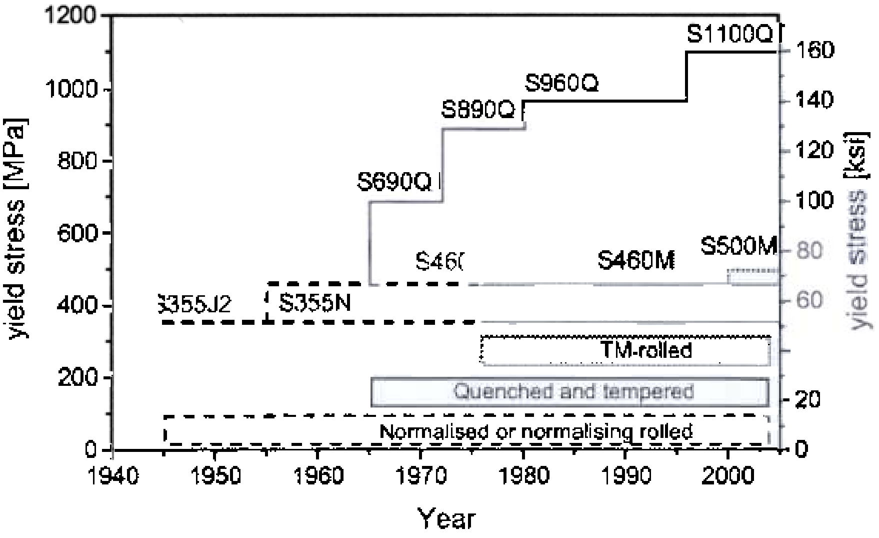


Fig. 9 Historical development of production processes for rolled steel products

During the 1960-s the application of the quenching and tempering process for structural steel grades began (process C). This process consists of a rolling followed by heating above the A_{c3}-temperature and a hard cooling, normally in water, plus a subsequent tempering below Ar_1 (temperature where austenite begins to form. See process C Figure 10). Roughly spoken during the first step a "strong" martenstic or baintitic grain structure is obtained whose toughness properties are significantly improved during the tempering process. Besides this heat treatment the good balance between strength and toughness is based on the fact that these steels are alloyed by adding microalloying elements (niobium, vanadium, titanium) precipitating as finely distributed carbonitrides.

Today this process enables steel grades with yield strength up to 1100 MPa, although only grades up to 960 MPa yield stress are standardised. Furthermore, European classical steel construction, i.e. buildings and bridges, profits only very rarely of these "ultra-high" strength steel and is mostly limited to steel grades up to S690.

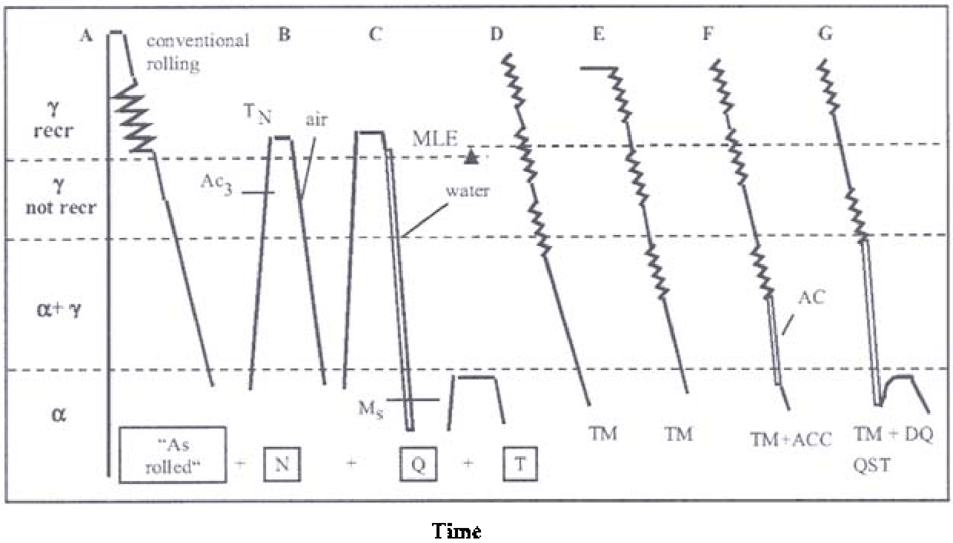
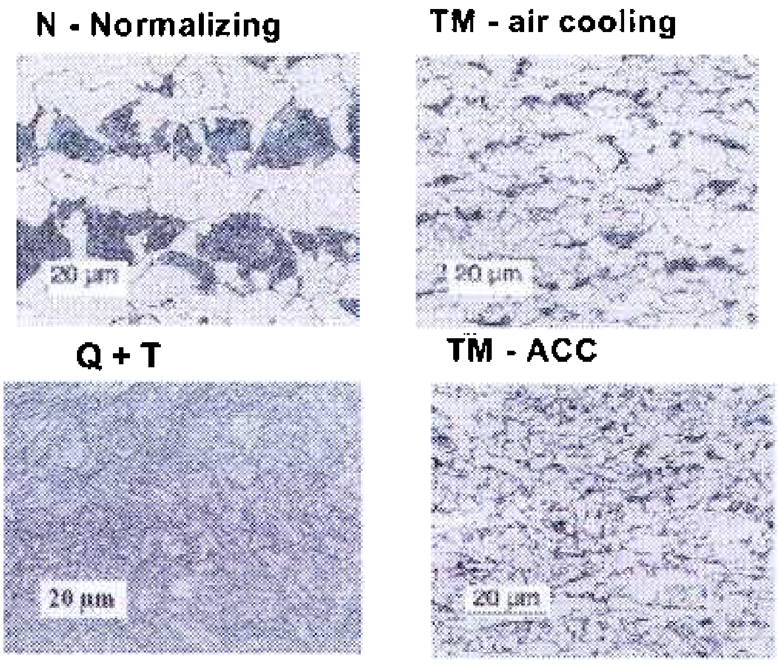


Fig. 10 Different types of heat treatment and rolling processes. Temperature on the vertical axis. γ recr denotes recrystallized austenite, γ not recr denotes non recrystallized austenite, α + γ the temperature range for austenite + ferrite and α the temperature region for ferrite and pearlite in conventional steels. MLE shows the increase in the temperature for recrystallization due to microalloying. T_N is the normalisation temperature

In the 1970-s thermomechanical rolling process was developed and first applied for line pipe plates, but then fast found the way into the fields of shipbuilding and construction of offshore platforms. TM-rolling is defined as a process in which final deformation is carried out in a certain temperature range leading to material properties which cannot be achieved by heat treatment alone. The resulting steel grade has high strength as well as high toughness and at the same time a minimum alloying content resulting in best weldability.

Also here it is usual to add to the steel some microalloying elements such as niobium, vanadium or/and titanium in a very small extent in order to achieve an additional strengthening effect by the formation of fine carbonitrides and to increase the recrystallisation temperature. First rolling passes are carried out at traditional rolling temperature. Further rolling passes are accurately defined at temperature below the recrystallisation temperature (process D) and sometimes even in the temperature range of coexisting austenite and ferrite/pearlite (process E). The process may be finished by an accelerated cooling especially for thicker plates (process F).

All these varieties of the TM-process produce a very fine-grained microstructure of ferrite and pearlite or – partly also bainite - as shown in Figure 11, avoiding high alloying content and therefore providing very good toughness properties and an excellent weldability. Furthermore high yield strength grades can be produced by these techniques. Plates with guaranteed minimum yield strength value up to 500 MPa are available in thickness up to 80 mm and are already used in shipbuilding and offshore construction [8]. For constructional steelwork even plates of 120 mm with up to 460 MPa yield strength have been produced and applied successfully in particular in bridges.



N - Normalizing

TM - air cooling

Q + T

TM - ACC

Fig. 11 Grain microstructure of QT and TM-steel compared to normalised steel

Higher-strength grades were not only developed in Europe but also in Japan and in the United States. The recent development in the United States, HPS-70W, will be discussed in detail in the following chapter.

3.2 Properties of high-strength grades

The maximum alloying contents for high strength steels as given in the standards are often considered to give very conservative upper limits. Actual values for the products are usually by far lower. Furthermore, it should be taken into account that not only the steel grade has an influence on the alloying content - moreover the chemical composition may vary with the thickness range. It is obvious that also differences between products of different producers are quite normal.

Table 1 gives examples of the chemical compositions of S460ML, S460QL and S690QL in comparison to the common European constructional steel S355J2. It can be seen that for grades up to S460 TM-rolled grades show a very "slim" chemical composition resulting in excellent weldability. But also the alloying concepts of the higher strength grade, in particular S690, allow for efficient fabrication processes, as described below.

It has to be clearly pronounced that the values guaranteed by the standards are minimum values. The user can normally expect considerably better values, in particular for toughness. Figure 12 displays as an example typical transition curves for the Charpy-V energy against the test temperature for a S460ML and a S690QL steel and compares them to a conventional steel, S355J2. It can be seen that these high-strength steels show significantly higher Charpy-V values at the testing temperature than given in the standard (27 J at -50°C and 30 J at -40°C respectively). Even at room temperature the toughness behaviour is better than for a conventional S355J2.

	S355J2		S460ML		S460QL		S690QL	
	EN 10025 Part 2	typical analysis[a]	EN 10025 Part 4	typical analysis	EN 10025 Part 6	typical analysis	EN 10025 Part 6	typical analysis
C	≤ 0.22	0.17	≤ 0.16	0.08	≤ 0.20	0.15	≤ 0.20	0.16
Si	≤ 0.55	0.45	≤ 0.60	0.45	≤ 0.80	0.45	≤ 0.80	0.30
Mn	≤1.60	1.50	≤ 1.70	1.65	≤ 1.70	1.50	≤ 1.70	1.30
P	≤ 0.025	0.018	≤ 0.025	0.011	≤ 0.020	0.012	≤ 0.020	0.012
S	≤ 0.025	0.015	≤ 0.020	0.002	≤ 0.010	0.005	≤ 0.010	0.005
Nb	-	-	≤ 0.05	< 0.04	≤ 0.06	0.017	≤ 0.06	<0.04
V	-	-	≤ 0.12	-	≤ 0.12	-	≤ 0.12	-
Ti	-	-	≤ 0.05	-	≤ 0.05	-	≤ 0.05	-
Mo	-	-	≤ 0.20	-	≤ 0.70	0.115	≤ 0.70	0.37
Ni	-	-	≤ 0.80	0.19	≤ 2.0	-	≤ 2.0	0.15
Cu	≤ 0.55	-	≤ 0.55	0.17	≤ 0.50	-	≤ 0.50	0.08
Cr	-	-	≤ 0.30	-	≤ 1.50	-	≤ 1.50	0.40
B	-	-	-	-	≤ 0.0050	-	≤ 0.0050	<0.003
CE	0.47	0.42	0.47	0.39	0.47	0.39	0.65	0.54
Pcm	-	0.26	-	0.19	-	0.19	-	0.29
CET	-	0.32	-	0.26	-	0.26	-	0.35

[a] Wide variation of the composition is possible due to a variety of possible production routes.

Carbon equivalents:

CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15

Pcm = C +Si/30 + (Mn + Cu + Cr)/20 + Ni/60 + Mo/15 + V/10 + 5B

CET = C + (Mn + Mo)/10 + (Cr + Cu)/20 + Ni/40

Table 1 Chemical compositions of high-strength steel, 50 mm thick (weight-%). S355J2 is given for comparison. Excerpt from the standard requirements and examples of actual values

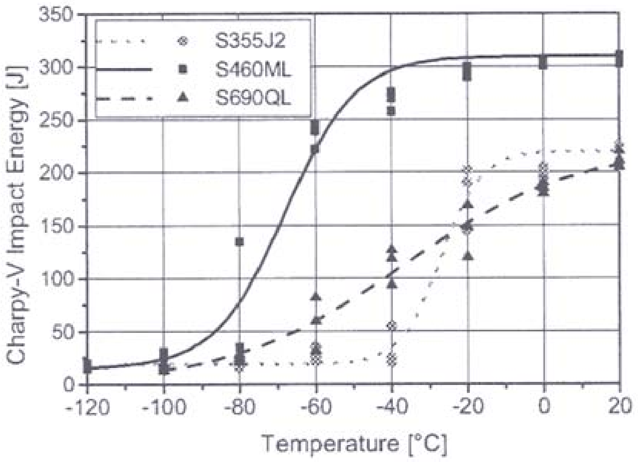


Fig 12 Charpy V-temperature transition curves for S460ML and S690QL with S355J2 for comparison

From the values in Table 1 it can be clearly shown, that the TM-process results in high yield strength at maintaining at the same time a favourable chemical composition. Furthermore, as stated above, these steels usually show excellent toughness properties. Together this results in very good welding properties of TM-steel, so that S460M is not harder to weld than a conventional S355J2-steel. On the other hand, quenched and tempered steel as S690Q show a much higher alloying content resulting in carbon equivalents demanding for special precautions during welding such as preheating, limited heat input to avoid to long cooling times etc. However, welding of such kinds of steel has already become routine in many machinery building branches such as crane industry.

3.3 Examples

The benefits of using high strength steel in bridgebuilding are clear: In comparison to normal strength steel the size of the cross section can be reduced resulting in

- a decrease of the dead weight of the structure, from which the substructure and the erection profit.
- reduced cross section of welded joints by which fabrication and inspection costs can be reduced and higher clearance heights under overpasses can be ensured.

For this reason higher strength steel are not only used for bigger landmark bridges but also for more convenient medium span bridges. It must be admitted that the application of higher strength steel is inhibited by the fatigue strength of welded details which is not superior to that of normal strength steel according to European construction standards. However, even high-strength steel can show advantages under fatigue loads for instance under overloads or if the welds are treated by a special post-weld treatment [9].

Figure 13 shows such a standard bridge, a bridge across a canal in Zuid Beveland, the southern part of the Netherlands. Here a girder construction of S460 was chosen in order to reduce the girder depth and to allow maximising the clearance height for the canal under the bridge

Fig.13 Bridge in Zuid-Beveland (The Netherlands)

A typical example for the application of S690Q-steel in medium span bridges in Germany is displayed in Figure 14. Here a composite bridge across the freight railroad centre in Ingolstadt with span lengths of 24 + 3*30 + 24 m is shown. The cross section consists of two 1.2 m-high plated girders in distance of 7 m, cross beams in a distance of 7.50 m and a cantilevered concrete deck cast in-situ in a rhythm of 15 m. Here S690Q was applied for the connection between the girder and the piers formed by concrete filled steel tubes of 600 mm diameter. The 70 mm-thick lamella of S690 was welded to the girder to form a bending-stiff connection. Thus, a very efficient alternative for bearings was created.

However, the real domain of high-strength steel grades such as S460M is still the construction of bigger bridges such as the new Rhine-bridge in the north of Düsseldorf (Germany), which was opened for traffic middle of 2002 [10]. For this cable-stayed bridge with a central span length of 275 m the pylons had to be restricted to a height of 34 m due to their situation in the landing zone of the near airport, see Figure 15. Therefore, the high forces arising in the pylon heads could only be solved by selecting the high-strength steel S460ML for these structural elements. Even plate thickness' up to 100 mm have been used for the central parts of the pylon heads.

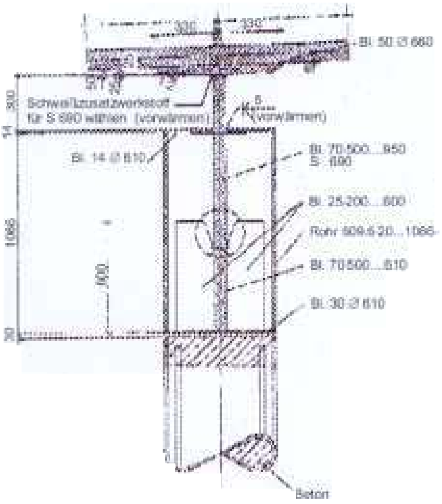


Fig. 14 Pier and pier-girder connection of a bridge near Ingolstadt

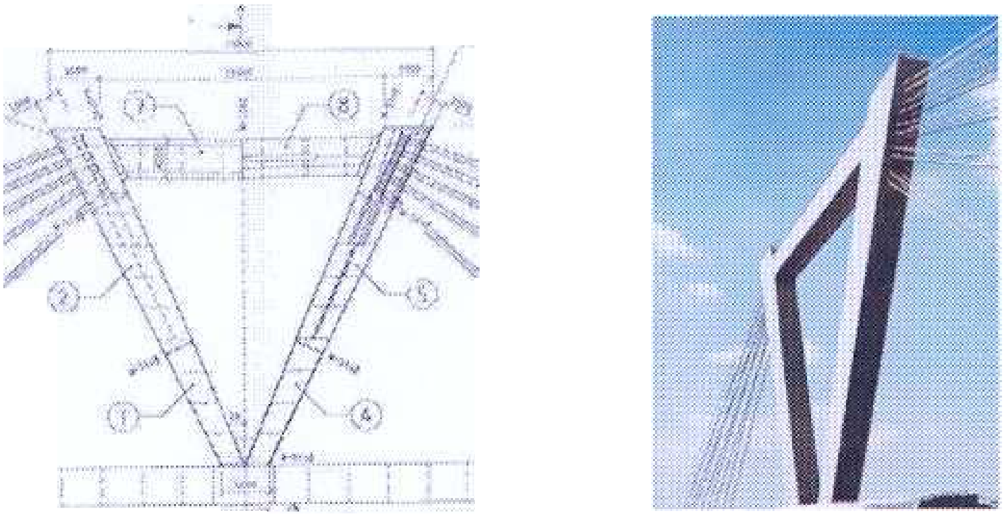


Fig. 15 Pylon of the new Rhine bridge Düsseldorf-North

For the Rion-Antirion cable-stayed bridge across the Gulf of Patras S460M (TM-rolled) is used for the plated girders of the composite deck in thickness' up to 80 mm. For thicker plates S460Q (quenched and tempered) was applied. Furthermore, the pylon heads have been designed of 700 t of S460M in plate thickness' up to 110 mm.

Thus, it is not astonishing that also as big part of the Millau-Viaduct was built by higher strength steel in particular S460M. From 43,000 t of heavy plates delivered for the deck and the pylon heads almost 18,000 was of S460M.

Also in Japan high-strength steel is widely used for landscape bridges. The American experiences are summarised in the following section.

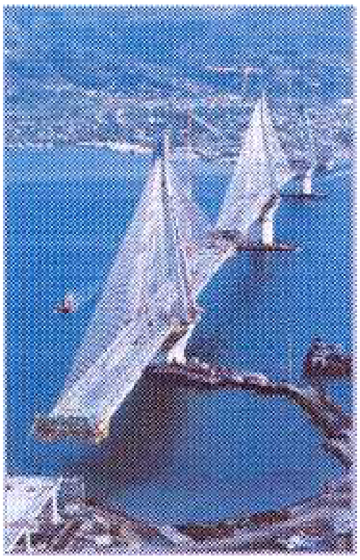


Fig. 16 Rion Antirion bridge

4. Weather-resistant steel

4.1 Metallurgy and construction

Weather-resistant steel are understood to be low alloy steels containing chemical elements which, under the condition of normal environmental circumstances, offer an enhanced resistance to rusting in comparison to ordinary structural steels. This kind of steel was developed during the 1930 in the United States and first used in railway coal wagons. During the 1960 these steels entered other structures such as steel and composite bridges. This improved corrosion behaviour is caused by the alloying by elements such as copper, chromium and in some cases also phosphorus. Of course, the last called element is not preferred due to its harmful influence on weldability. In ASTM G 101 [11] an index I is derived by which the weathering behaviour can be judged:

$$\begin{aligned} &= 26.01\,(\%Cu) + 3.88\,(\%Ni) + 1.20\,(\%Cr) + 1.49\,(\%Si) + 17.28\,(\%P) \\ &\quad - 7.29\,(\%Cu)(\%Ni) - 9.10\,(\%Ni)(\%P) - 33.39\,(\%Cu)^2 \end{aligned} \qquad (1)$$

Under normal atmospheric corrosion conditions a minimum value of 6.0 should be reached to ensure sufficient corrosion behaviour.

Weather-resistant steels do not prohibit rusting at all. Contrarily to conventional structural steel they form an oxide layer which is sufficiently impervious and tightly adhering so that it becomes a barrier restricting further ingress of moisture and oxygen to the metal and the rate of corrosion diminishes. This can be seen in Figure 17.

Weathering steels perform best in locations where alternative wetting and drying occurs, that means in most urban and rural conditions. However some environments may not be suitable for the application of weathering steel:

- industrial atmospheres with concentrated corrosive chemical, for instance exceeding 2.1 mg of SO_3 per 100 cm^3 per day.
- locations, where the steel rests continuously wet or damp. This may occur when members are submerged in water, buried in the ground or covered by vegetation.

- atmospheres, where the steel is exposed to high concentrations of chloride ion mostly occurring next to the coast.

Therefore, it is easy to understand that bridge design with weathering steels must avoid all kind of detailing where moisture can accumulate and no drying is enabled. The designer must therefore exercise care in the detailing ensuring that they are well-ventilated and self-draining with no possibility of moisture entrapment.

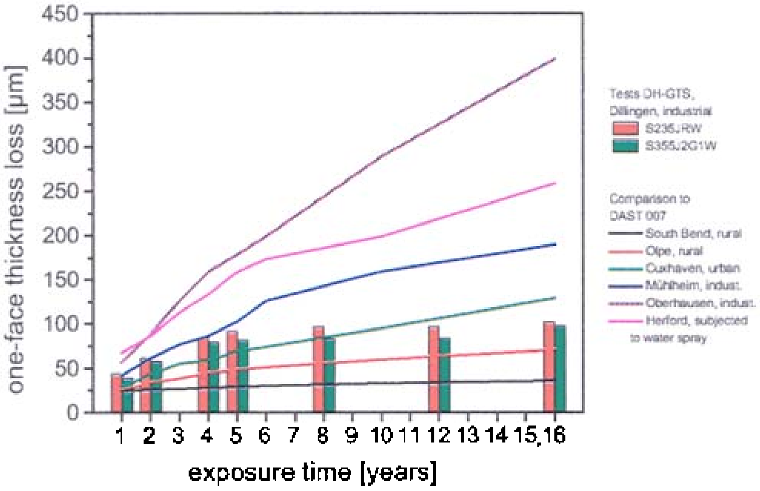


Fig. 17 One-face rusting of weathering steel in various atmospheres

Furthermore, the forming of the self-protecting oxide layer is considered by most national design codes by a thickness addition on each side of the construction, as the layer forms during the lifetime and does not carry loads. For instance, the German rules [12] provide an additional thickness of 0 mm in rural areas and of 1.5 mm per face in a more industrial atmosphere if a life time of 30 years is required.

4.2 Benefits

By the application of weathering steel cost reduction and other benefits in various phases may be possible [13]:

- Initial costs: Although weathering steel and also consumables and bolts to fabricate a structure are more expensive compared to normal structural steel, these additional costs can be smaller than the coast of a comprehensive protective coating system, which can account for up to 10 % of the cost of the steel structure. Typical extra costs for the usage of weathering steel are given in Table 2. Using a typical average surface area/mass ration of 10 m²/tonne, this results in extra cost of 20 to 25 Eur/m², which is cheaper than the cost for a not too simple protective system.
- Reduced construction time: The omission of painting also results in a reduced time of construction.
- Reduced cost for maintenance: The major advantage of using weathering steel in bridges is usually derived by the reduction of maintenance costs. Normally only some inspection and cleaning will be required to ensure that the bridge performs successfully. However, these costs are normally negligible compared with costs of regular repainting.
- Reduced time of maintenance operations: Due to less efforts for inspection and repainting, the maintenance procedure is easier so that traffic delays are reduced whilst maintenance operations are carried out.

Environmental benefits: Painting can be harmful to the health of the operatives and can also cause environmental damage.

	Extra costs in Eur/t	
Additional thickness per surface	+ 1 mm	+ 2 mm
Extra for weathering steel	80	80
Cost of extra thickness	46	93
Fabrication waste at costs of weathering steel	4	4
Extra for consumables	11	11
Additional blast-cleaning	34	34
Extra for weathering bolts	28	28
Total	**203**	**254**

Table 2 Typical extra costs of using weathering steel

These benefits are already widely used in plenty of countries, in particular for bridges in more rural areas. Whereas weathering steel bridges are still quite unusual in France and Germany, the share of bridges made of weathering steel are increasing in Great Britain and Italy. Figure 18 shows an example for such a bridge in Great Britain. Also in the United States and Japan weathering steel is quite popular. In the first mentioned country this steel has already reached a share of almost 50 % in steel and composite bridges. Some developments in these countries will be described in the following sections.

Fig. 18 Weathering steel in the River Tale Bridge (span: 27 m)

4.3 HPS70W - an American development

In the United States a new type of steel has been developed from the middle of the 1990 by a co-operation of the Federal Highway Agency (bridge owners), the American Iron and Steel Institute (steel producers) and the Department of the Navy. The first of these steels is ASTM A709 Grade HPS-70W, known simply as HPS-70W, which has already become a real success story. HPS-70W is defined as plate in a thickness up to 100 mm as a weather-resistant steel with a minimum yield stress of 100 ksi (485 MPa) with a higher level of fracture toughness in comparison to standard ASTM steel grades. Furthermore a chemical composition is chosen in order to improve weldability by reduced preheating temperatures. Table 3 defines the chemical composition and mechanical properties of this steel.

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Al	N
≤ 0.11	1.15 - 1.30	≤ 0.020		0.35 - 0.45	0.28 - 0.38	0.28 - 0.38	0.50 - 0.60	0.04 - 0.08	0.05 - 0.07	0.04	

Tensile test			**Charpy-V Test at -23°C**	
Yield Stress R_{eh} [MPa]	Tensile Strength R_m [MPa]	Elongation [%]	Average of 3 samples [J]	Single value [J]
≥ 485	620 - 760	19	48	38

Table 3 Chemistry and mechanical properties of HPS-70W

HPS-70W is produced by some mills by the TM-process in thickness' up to 50 mm. For thicker plates the quenching and tempering process is usually applied. In order to give an example of the mechanical properties, Figure 19 displays the toughness values measured by the Charpy-V-specimen at -23°C at plates of 25 mm thickness. It can be seen that toughness values are usually quite higher than the requirements set in the standard.

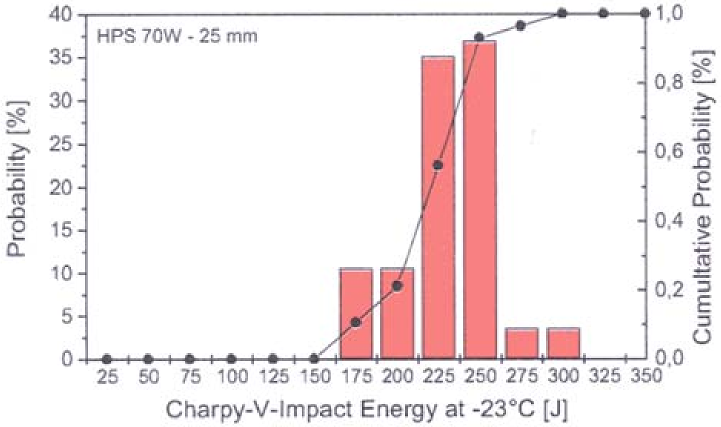


Fig. 19 Typical Charpy-V-values of HPS-70W

Fig. 20 HPS-70W in bridge next to Springfield, Nebraska

After bringing the first bridge in service 1997 it is estimated for 2004 that more than 150 bridges in the United States will be built with HPS-70W. Figure 20 shows an application of HPS-70W next of the town of Springfield in north central Nebraska, a composite bridge with four longitudinal girders spaced in a distance of 3 m. The steel alternate, with two end spans of 43 m and a middle span of 53 m, was comprised of four lines of welded plate girders with a parabolic haunched section at each pier. Here a normal ksi 50 steel is used for the girder regions with positive bending moment, whereas HPS-70W was been used in a hybrid construction in the flanges with normal ksi 50 steel in the webs in the negative moment areas [14].

Today, also an HPS-100W grade has been developed in the United States, a weathering steel with a minimum yield stress of 100 ksi (690 MPa) by which first projects have already been realised.

4.4 Developments in Japan

The use of high-performance steel, by which either high-strength steel or weathering steel is understood, is continuously increasing in Japanese bridge applications. For example the amount of weathering steel used in 1990 was less than 30,000 t/year, whereas it reached, in 1998, already 100,000 t. The total steel volume for steel and composite bridges is estimated to be approximately 600,000 - 700,000 t.

However the more frequent application of weathering steel is hampered by the fact, that according to Japanese rules this kind of steel can only by used in an atmosphere where the content of airborne salt does not exceed 0.05 mg/dm²/day. Therefore weathering steel is applicable in Japan in regions not closer than 2 kilometres from the Pacific Ocean, 5 kilometres from the southern part of the Japanese See and 20 km from the northern part of the Japanese sea. However, most infrastructure project are closer to the ocean. To overcome this problem, a new weathering steel with better performance in corrosion resistance in particular in severe coastal conditions was developed.

Therefore a comprehensive study on the impact of alloying elements was performed. As a result weathering steel types SMA490W-mod and SMA570WQ-mod have been designed with a nominal tensile strength of 490 MPa and 570 MPa respectively. The standard chemical composition is given in Figure 4. It can be noticed that, in comparison to American and European standard weathering steel grades, the alloying content of chromium is much more smaller, whereas the content of nickel is significantly increased to value even above 3.0 %. It should not be neglected that addition of nickel significantly increase the cost of the steel due to high purchase price of these alloying elements. Therefore the above mentioned economical comparison cannot applied here as cost for the steel input material are much more higher for this new steel.

C	Mn	P	S	Si	Cu	Ni	Cr
		≤ 0.035	≤ 0.035	0.15 - 0.65	[illegible]	[illegible]	

Table 4 Standard chemical composition of SMA490W-mod and SMA570WQ-mod

However, the positive impact on corrosion resistance was approved by a nine year exposure test as shown in Figure 21.

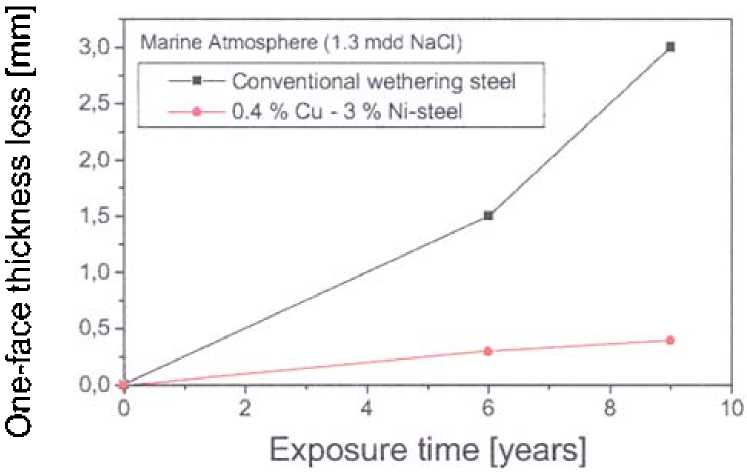


Fig. 21 Comparison of corrosion between conventional weathering and new Japanese development in marine atmosphere

5. Conclusion

This article highlights the recent developments made by the steel industry in Europe, America and Japan in order to supply steel and composite bridges with more efficient products. These developments have been categorised into three big trends:

- dimensions, in particular thicker plates for bridges with reduced costs for detailing,
- high-strength steel for a reduction of fabrication costs and
- weathering steel for improved maintenance behaviour.

It is not surprising, that these developments are a little bit similar between the single countries. However, other obstacles may exist in the single countries which may hinder the utilisation of these efficient steel products, for instance ancient building regulations penalising or even forbidding the use of these products. However, countries with such an attitude can strongly benefit from experiences made in other countries, where these "new" materials are already introduced widely in the market. Thus, for instance in Norway more than half of all steel bridges use high-strength TM-rolled steel, whereas these steel are used still only in special constructions in Germany and are more or less unknown in Italy. Why Great Britain uses plenty of weathering steel for bridges (although not known for a sunny climate), whereas only very few bridges are built in weathering steel in Germany or France?

These simple example shows that steel bridge design in a particular country can not only profit form "new" material offered - it can also profit from the experiences made with these materials in other countries. Let's use it to built more efficient, safe and also beautiful bridges.

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