APPLICATION OF DUPLEX STAINLESS STEEL FOR WELDED BRIDGE CONSTRUCTION IN AGGRESSIVE ENVIRONMENT

G. Zilli, F. Fattorini, E. Maiorana

Paper presented at the International Conference Duplex 2007, Grado, Italy, June 2007, organised by AIM

Maintenance costs are a significant item in life cycle of steel bridges, becoming of paramount importance in aggressive environments. The use of duplex stainless steels for bridge decks would be a major step forward in providing durable, low maintenance structures, exploiting both their corrosion resistance and high mechanical properties, capable of meeting in full the required structural safety performances. A research project partially funded by the EU research programme RFCS (Research Fund for Coal and Steel, Bridgeplex contract RFS-CR-04040) is developing technical information on the use of duplex stainless steel in welded bridge construction via mechanical testing and numerical analyses, so as to provide indications suitable to form the basis for an upgrade of Eurocode 3 [1] and to allow a reliable Life Cycle Cost analysis for this kind of structures so as to address the best material choice for the future bridges.
The project is still in progress but first results are available. This paper gives an overview of the project and summarizes results obtained, deeper detailed in other papers presented at the International Conference Duplex 2007 ([5] and [6]). In particular the paper is concerned with:
· overview of critical details in a welded bridge deck and relevant data available in literature also on austenitic and austeno-ferritic steels; and
· economical evaluations considering maintenance aspects and fabrication costs showing the advantages of the application of duplex stainless steel to defined bridge typologies.

Keywords: duplex, stainless steel, bridge, construction, life cycle cost, maintenance

INTRODUCTION

Service life beyond 100 years is today the target of major infrastructure projects in the world, such as the longer and longer metallic suspension bridges. The capital investment involved is very high and planned maintenance costs are of overall importance for the return on investment. Both safety and reliability become also of paramount importance because any temporary closure is very expensive both in direct maintenance and repair and in traffic interruption.

Giuliana Zilli
Centro Sviluppo Materiali s.p.a., Italy
Francesco Fattorini
Centro Sviluppo Materiali s.p.a., Italy
Emanuele Maiorana
OMBA Impianti & Engineering s.p.a., Italy

The aforementioned reasons lead to strongly consider duplex stainless steels as construction material owing to their expected intrinsic corrosion resistance also in very aggressive atmosphere, assured by their chemical composition (22Cr 5Ni 3Mo 0.2N), and their high mechanical resistance due to their austeno-ferritic microstructure.

Together with its intrinsic high cost, a major barrier to the use of duplex stainless steel in welded bridge construction is the lack of experimental data on both their mechanical characteristics and technological feasibility with respect to the specific application, properties to be assessed if compared with the vast know-how available for traditional carbon steels.

This paper will present an overview of the whole research activity ongoing in the frame of RFCS programme, highlighting the aspects investigated for the promotion of the use of duplex stainless steel in bridge construction. While specific technical aspects related with the ability of duplex stainless steel

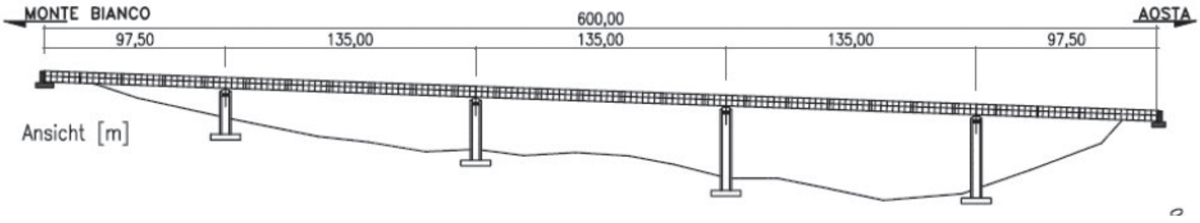


Fig. 1

Verrand viaduct view.

Viadotto Verrand a trave continua in lastra ortotropa (realizzato da OMBA).

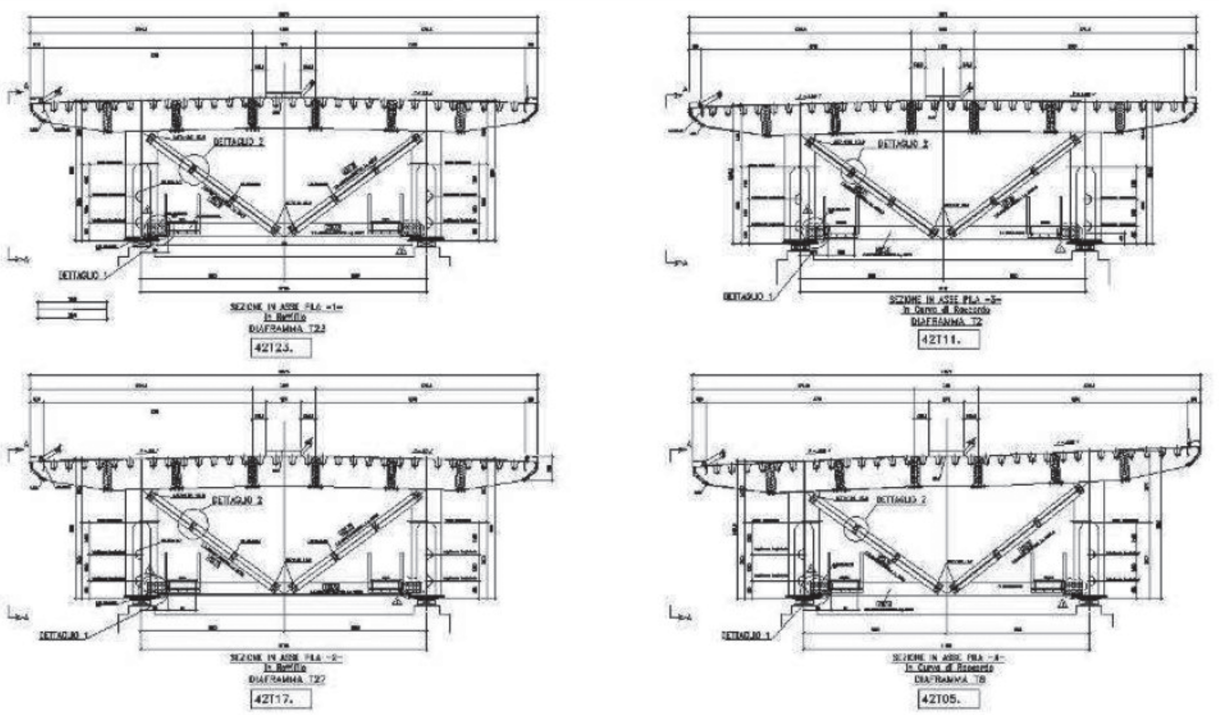


Fig. 2

Transversal section of the Verrand viaduct.

Sezione trasversale di lastra ortotropa (viadotto Verrand, OMBA).

to satisfy the bridge design requirements are here only introduced as their results are reported in other papers presented at the International Conference Duplex 2007 ([5] and [6]), here an overview of questions addressed and their effects in the view of Life Cycle Cost (LCC) evaluation are presented.

CHOICE OF A BRIDGE CASE STUDY

Steel bridges are increasingly using complex welded steelwork solutions to emphasise the lightness and aerodynamic shaping steel construction can offer. In this view the most diffuse constructional typology, especially used in long span bridge deck construction, is the orthotropic deck.

The boom of great bridges of the 1990's concerns long-span suspension bridges.The main span length of cable-suspension bridges is nearing 2 km, which is currently more than twice that other bridge types can reach. The most long span suspension bridges with the longer central span in the world (the Akashi Kaikyo Bridge, with central span of 1991 m and the Storebaelt East Bridge, with central span of 1624 m), finished at about one year time distance each other, are representative of two different constructive typologies of bridge: although both employ an orthotropic deck, due to the different cross-section geometries (one is a truss cross section while the other is a box section) have also two different flexural and torsional stiffeners and, consequently, different responses to the wind action [7].

It is important to note that with a similar constructive technique (orthotropic deck), are realized also bridges with medium length of span (from 100 m) as results from an overview of the most significant bridge typologies . Orthotropic deck is identified as the most interesting for the scope of this investigation: that bridge typology contains all the critical welded details of the other bridge typologies and some other specific of orthotropic deck bridge.

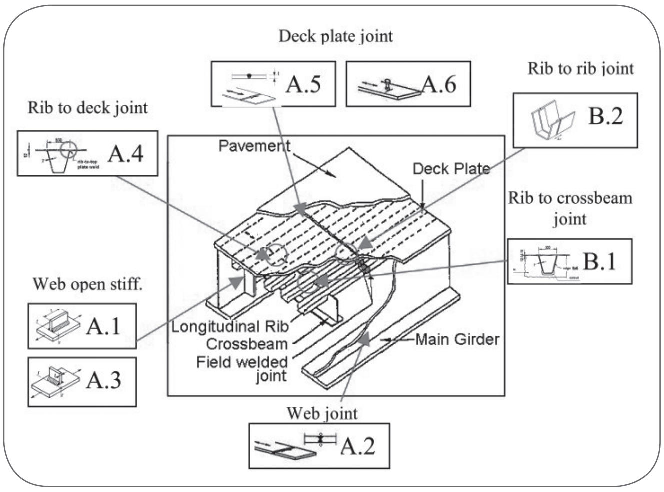


Fig. 3

Welded details in orthotropic deck bridge.

Dettagli saldati di una lastra ortotropa.

Consequently many research projects and experimental activities have been devoted in the recent past to study the in service behaviour of this complex steelwork leading to design and execution recommendations. But all of them were developed and verified on traditional constructional steel grades (i.e. S355 [8], [9], [10] and [11]).

Although the duplex basic mechanical properties are well known, it is not enough to promote this material for huge welded bridge construction but, because of the relevance of such a structure, more specific investigations on structural components typical of bridge structure are needed. Presently it is not possible to propose stainless steels for welded bridge construction without having a similar experimental evidence of their applicability, although from the LCC point of view these materials could have some advantages with respect to the more traditional solutions, when the expected service life is prolonged beyond two big maintenance intervention [12].

The existing bridge chosen to have a comparison between the utilization of carbon steel and duplex stainless steel, considering both mechanical behaviour and durability during the whole service life with the scope of evaluating its Life Cycle Cost (LCC), is the Verrand viaduct (Fig. 1 and Fig. 2, [13]).

The Verrand viaduct whose owner is R.A.V. spa, built in 2000 by OMBA of Torri di Quartesolo (Vicenza, Italy), is part of the Mont Blanc-Aosta highway, connecting Mont Blanc Tunnel with Morgex. The finishing of this part has permit to go to the Tunnel by an highway broad. The viaduct needed the realizations of long length spans, to have few intermediate piers, as for geodetics problems as to leave untouched the environmental and panoramic view: the Dora Baltea valley.

CRITICAL DETAILS IDENTIFICATION

Fatigue

The bridge deck is the structural part mainly subjected to cyclic loads (both railway and roadway actions) so as in many cases Fatigue Limit State [1] is the relevant one in design phase. Bridge deck can be made of different construction typologies but orthotropic deck is the most significant one in terms of fatigue problems: it presents a great number of welded details and some of them are particularly complex.

An orthotropic deck consists of prefabricated deck modules welded at factory and joined together on site also by means of welding. The top plate joints are always welded on site, while beam elements joints can be either bolted or welded.

In the transversal section of the Verrand bridge steel deck (Fig. 2,double-beam orthotropic deck) the transversal beams (T shaped section) are bolted; diaphragms and braces are made of bolted T or L profiles. Its static scheme is the continuum beam on a few supports. In Fig. 3 are shown the welded details selected for fatigue testing in the research project, results are presented in the paper [6] at the International Conference Duplex 2007. Here below some of those are described also giving details on fabrication and welding procedures adopted, all being in accordance with bridge construction practice and needs:

- The edges of the top plate to be joined on site are usually butt welded with a back ceramic support without backing run, to avoid the finishing of the weld on the back side. In that case the welding process is mixed: a first pass using the semi-automatic MAG – FCAW and the following passes (2nd4nth) by the automatic SAW process. Clamps are needed to align the plates and to keep the back ceramic support. The clamps are bolted to threaded studs welded on the bottom edge of the top plate, close to the edges to be joined (see Detail A.5 and A.6 of Fig. 3).
- Corresponding to the transversal top plate joint of the deck modules it is necessary also to replace the continuity of the longitudinal ribs of the orthotropic deck: the way is to butt weld on site a piece of rib using a support plate (see Detail B.2 of Fig. 3).

Large effort was made in the past for assessing the fatigue design curves of full-scale components typical of orthotropic deck, leading also to design indications incorporated in Eurocode 3 [1] for design of steel structures. Eurocode 3 [4] proposes the S-N curves approach for fatigue design, and it classifies a set of structural details assigning them specific design S-N curves. These curves were defined on the basis of historical experimental data collected initially for carbon steel details, the most general were also verified for a few stainless steel grades. Not so for structural details typical of orthotropic deck.

Buckling

Typical elements of steel bridges, i.e. the main longitudinal beams (Fig. 4), have very high web subjected to both bending and transversal concentrated loads.

Web buckling is a primary design

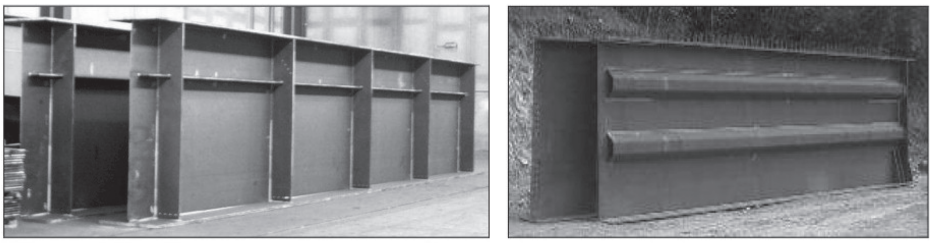
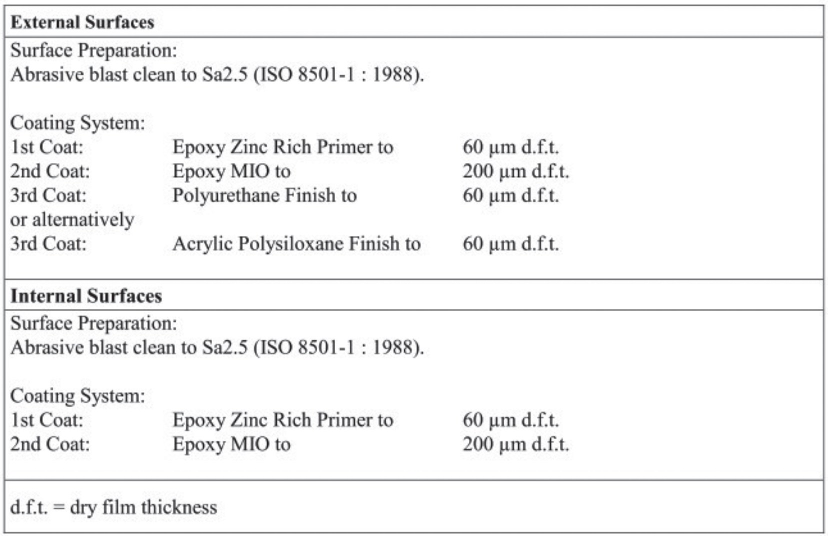


Fig. 4

Bridge girders with open section (left) and close section (right) stiffeners.

Travi longitudinali con anima irrigidita.



External Surfaces		
Surface Preparation: Abrasive blast clean to Sa2.5 (ISO 8501-1 : 1988).		
Coating System:		
1st Coat:	Epoxy Zinc Rich Primer to	60 µm d.f.t.
2nd Coat:	Epoxy MIO to	200 µm d.f.t.
3rd Coat:	Polyurethane Finish to	60 µm d.f.t.
or alternatively		
3rd Coat:	Acrylic Polysiloxane Finish to	60 µm d.f.t.
Internal Surfaces		
Surface Preparation: Abrasive blast clean to Sa2.5 (ISO 8501-1 : 1988).		
Coating System:		
1st Coat:	Epoxy Zinc Rich Primer to	60 µm d.f.t.
2nd Coat:	Epoxy MIO to	200 µm d.f.t.
d.f.t. = dry film thickness		

▲ Tab. 1

Paint system for general surface, corrosion category C 5.

Sistema di protezione dalla corrosione per una superficie generica in acciaio da costruzione e corrosività ambientale di categoria C5.

criterion for such a structural element. Moreover, the repetitiveness of low load levels, apart from fatigue problems, can get an unsafe accumulation of plastic strain due to the non-linearity of the s-e curve before the conventional yielding stress Rp0.2%.

As results from an overview of data available in literature on ultimate shear resistance (Vult) of plate girders only a few tests are performed on stainless steel girders. It means that the now available design methods [3] are established especially on the basis of traditional carbon steel behaviour although stainless steel has clearly different mechanical properties related to its anisotropic and nonlinear behaviour.

The ultimate shear strength of plate girders with a slender web is especially contributed by the so- called post critical strength reserve, which develops once the shear stress in the web has reached the elastic critical shear buckling stress. All the models developed for the evaluation of the ultimate shear resistance are based on a similar basic idea according to which this resistance is composed of two main contributions:

- The "web contribution" , i.e. the elastic critical shear buckling resistance of the web;
- The so-called "flange contribution" reflecting the fact that, once the web has buckled, the web is still able to act as a pseudo-diagonal of a truss member, the chords of this member being the flanges and the vertical struts being the transverse stiffeners.

Once developed, these models were calibrated against a lot of experimental results obtained from tests on specimens made of carbon steel.

The ultimate shear resistance of a slender I (unstiffened or transversely stiffened) plate girder may exceed very significantly the elastic critical shear buckling resistance of the web by an amount which depends on both web slenderness and rigidity of the flanges. Of course the account for post-critical strength reserve is beforehand subordinated to the requirement of sufficient ductility for the steel material that is well known to be a characteristic favourable to duplex stainless steel.

In the ongoing project both experimental activities and numerical analysis are in progress to evaluate the performances of EN 1.4462 duplex stainless steel in the application to bridge girders construction but results are not yet available.

Corrosion resistance

Looking at the aggressiveness of sites, EN ISO 12944 Standard classifies five different growing levels, from C1 to C5. C5 comprises also a marine site with presence of aggressive pollutants, as the environment of suspension bridges in Japan, in Hong Kong and of the future Messina Strait Bridge can be classified.

Corrosion rate of carbon steel in C5 sites is very significant and expected around 80-200mm/year.

As a consequence, to preserve the structure costly measures as long lasting painting coating of both external and internal surfaces and/or continuous dehumidification of closed volumes (with R.U.* 40% weathering corrosion rate is practically suppressed) are used. In Tab. 1 an example of such an high protective coating system is reported.

EN 1.4462 duplex stainless steel grade selected for this applied research activity (UNS S32205 produced by Industeel) is demonstrating the attitude to be applied without any corrosion protection, also in class C5 environments and considering welding techniques for the specific application, as reported in the paper [5] of the Conference.

Comparing life-cycle costs of alternative materials

The life-cycle cost (LCC) is evaluated on the basis of ASTM E917-05 "Standard practice for measuring life-cycle costs of buildings and building systems" [16]. LCCs of alternative structural material choice for the same bridge deck are compared. In particular EN 1.4462 unprotected stainless steel is taken as an alternative to S460 painted steel.

Experimental activities performed during the research project confirmed the duplex stainless steel alternative material satisfies the project requirements (structural safety and integrity, reliability, environmental) under the same operational conditions of Verrand bridge but considering a class C5 environment. That is a fundamental assumption when comparing the LCCs of alternatives in general.

Considering the attitude of duplex stainless steel to be placed in service without any corrosion protection, that is also in very aggressive environments classifiable as C5 (EN ISO 12944), the most sensitive parameters to be assessed in LCC analysis are those related with corrosion protective systems and their maintenance (cost of protective coatings, the cost and frequency of inspections and maintenance actions). With this respect it is important to note that those parameters are influenced by bridge owner standard practice and can vary by country to country, also technical knowledge is always in progress and new protective systems can arise at the market. As a consequence in the fol-

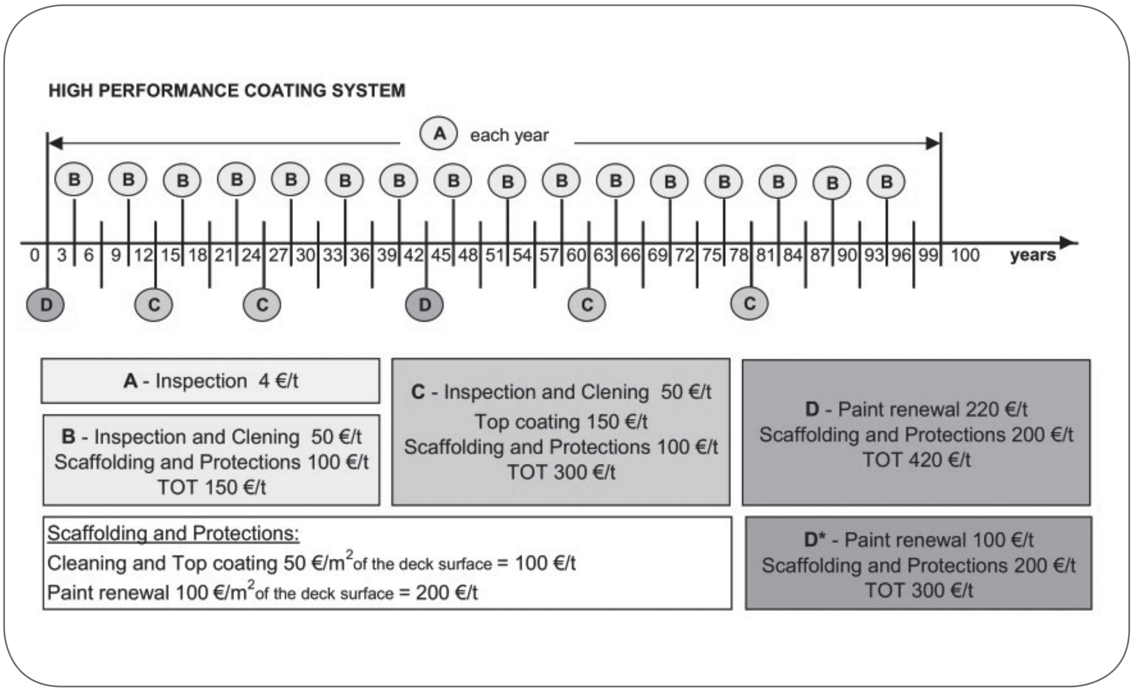


Fig. 5

Maintenance timing of painting systems for S460 of two different performance levels.

Programma d'ispezione e manutenzione per la protezione dalla corrosione di ponti metallici in ambiente di categoria C5.

lowing LCCs analysis a protective system for S460 steel bridge is considered which is among the more traditional ones due to the easier availability of data on. Maintenance scheduling is reported in Fig. 5.

Some effects of alternative materials highlighted during both the fabrication of steelworks for testing and the evaluation of test results, are economically assessed in the present LCC analysis

As regard the shop and yard productivity, the cost of austeno ferritic is considered 15% higher that follows by the balance between the faster welding rate and the more expensive welding and cutting operations (see also paper [5] of the Conference).

The total quantity of the two material is the same as for the carbon steel bridge as for the duplex bridge in accordance with the available mechanical test results. The increment in the fatigue behaviour of the austeno ferritic s.s. welded details shown by the testing activities [5] is assessed in the following LCC evaluations by not considering repair for fatigue costs during service life of duplex bridge. Only inspection (each year) and cleaning (every 9 years) are considered in the LCC evaluation of duplex alternative.

Some of the effects of alternative materials are more difficult to quantify in monetary terms, that is the case of users costs related with the reduction of speed or complete closure of the bridge. For example German Steel Association evaluates for ordinary maintenance operations 20 days of speed reduction from 120 km/h to 60 km/h, while for exceptional maintenance operations 40 days of speed reduction are expected. What this means in monetary terms is also difficult to be further evaluated but this aspect should be listed with the others and taken into account in the final evaluations.

The LCCs of both bridge alternatives are calculated in present-value that means all costs are discounted to the base time (time of bridge construction). The study period is the expected service life for the bridge that is 100 years. LCC analyses are calculated in constant monetary value (net of general inflation). Bridge is treated as public utility infrastructure (non-profit building) so income tax effects are not included in the LCC analysis. The discount rate is a very sensitive parameter for LCCs comparisons with money savings mostly spreaded into the future, as in the present case study.

Here two different real discount rates (net of general price inflation) are used in the LCCs analysis:

Study period	100 years
Real discount rate	3.2% and 1.8%

<u>Investment cost data</u>	S460	EN 1.4462
Material cost	1'100 €/t	5'500 €/t (2006 price)
		3'000 €/t (2001 price)
Shop cost	320 €/t	420 €/t
Yard assembly cost	160 €/t	185 €/t
Assembly equipments	200 €/t	200 €/t
Corrosion protective coating	35 €/m^2	0

Scaffolding and protections included

<u>Maintenance cost data</u>		
Inspection	4 €/t	4 €/t
Cleaning	50 €/t	-
Top coating (high performance system)	25 €/m^2	-
Coating renewal	35 €/m^2	0

Scaffolding and protections included

Repair for corrosion (% of initial investment)	5.16%	-
Repair for fatigue (% of initial investment)	12.3%	-

User costs related with reduction of service or closure of the bridge during maintenance operations are not monetary evaluated but should be taken into account in the comparison.

End of service resale	S460	EN 1.4462
	30%	75%
	of material cost	

The results of LCC evaluations are reported and compared in

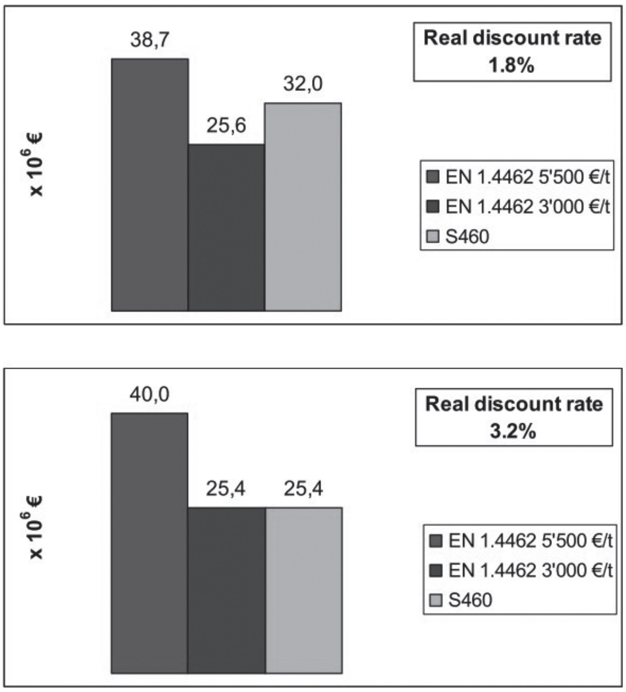
Fig. 6 and Fig. 7, the first figure shows the costs after 100 years of service life while the latter shows the time of recovery of initial investment using EN 1.4462 duplex stainless steel instead of S460 carbon steel.

CONCLUSIONS

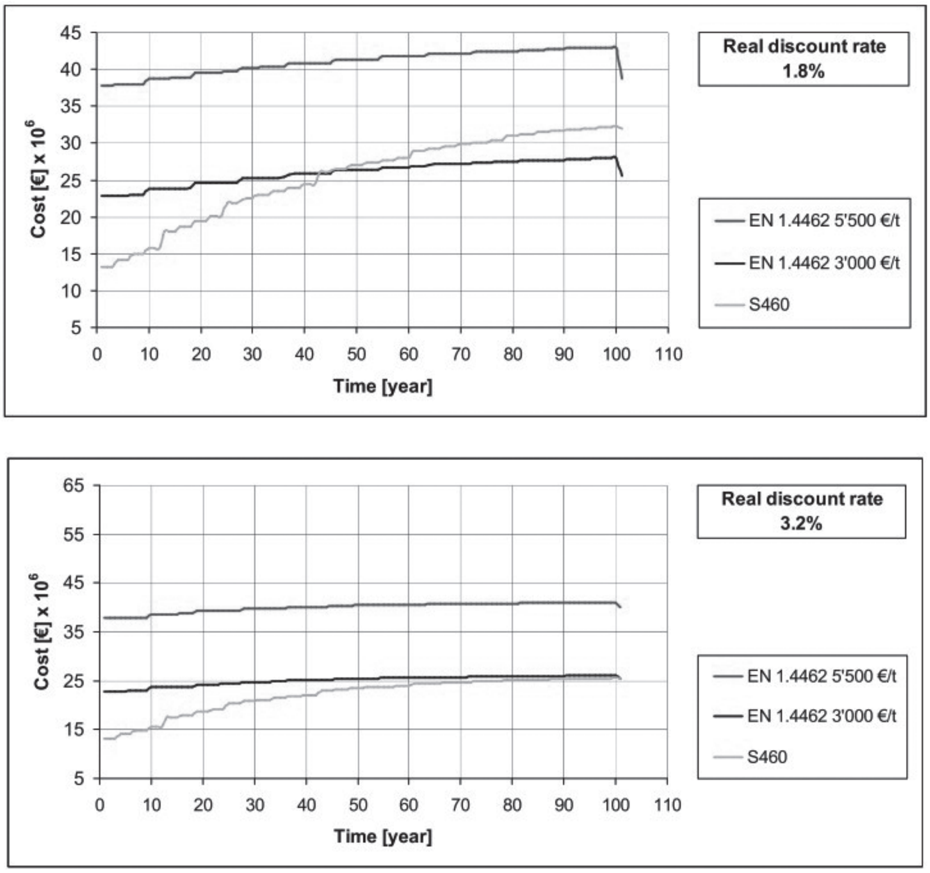
LCCs of a steel bridge deck in aggressive environment (class C5 EN ISO 12944) were evaluated comparing EN 1.4462 duplex stainless steel grade with traditional high strength structural steel S460. Some difficulties in the comparison are highlighted:

- the evaluation of a consistent discount rate especially considering the long service life (100 years): in the present analysis two different discount rates are considered;
- the variation of the price of duplex stainless steel: since 2001 the price changed from 3'000 €/t to 5'500 €/t; and
- the evaluation in monetary terms of some effects of the material alternatives, in particular the user cost related with reduced traffic or closure of the bridge.

Taking into account all these limits of the LCCs evaluation the comparisons reported in Fig. 7 show that initial investment cost of high performance material can be recovered for money savings during service life when duplex cost is not over 3'000 €/t (2001 price) while if the price reaches the level of 5'500 €/t (2006 price) the LCC of the bridge is from 21% to 57% higher than using an S460 steel (depending on discount rate variations), that is not so bad considering that in this evaluation duplex costs 400% more than S460 steel and also some advantages related with the use of duplex are not considered



▲ Fig. 6
Whole service life costs.
Costo dell'opera nell'intero ciclo di vita.



◀ Fig. 7
Recovery time of the initial investment.
Curve dei costi durante il ciclo di vita.

in the model due to the difficulty of their monetary evaluation (i.e. end user costs related with the bridge closure during maintenance operations).

We have also compared two different discount rates: supposing the price of duplex is 3'000 €/t as in 2001, considering the less favourable discount rate (3.2%) we obtained quite same building cost at the end of service life while initial investment is recovered after about 50 years of service when considering a more favourable discount rate (1.8%) is obtained. Moreover in the comparison user costs related with reduction bridge service during maintenance are not monetary evaluated.

In conclusion duplex stainless steel has many attractive characteristics for bridge construction: corrosion resistance, high strength and also aesthetics ones. All of those where demonstrated for the specific application during the research project. Duplex stainless steel can be also economically attractive when considering whole service life costs: initial capital expense is recovered after 50 years of service, provided that producers can keep the price into the lower level of the last years (i.e. 3'000 €/t).

ACKNOWLEDGEMENT

The authors wish to express their deep gratitude to the European Commission for its financial support and to the representatives of the other partners from INDUSTEEL Le Creusot and from RWTH Aachen for their cooperation.

REFERENCES

1] ENV 1993-1-1. Design of steel structures. General rules – Rules for buildings.
2] ENV 1993-1-4. Design of steel structures. General rules – Supplementary rules for stainless steels.
3] ENV 1993-1-5. Design of steel structures. General rules – Supplementary rules for planar plated structures without transverse loading.
4] ENV 1993-1-9. Design of steel structures. General rules – Fatigue design
5] A. FANICA and E. MAIORANA, UNS S32205 for bridge construction: an experience of application", Duplex 2007 Int. Conf. Proc. Grado, Italy (2007).
6] O. HECHLER, M. FELDMANN, R. MAQUOI and G. ZILLI, Bridge construction made in duplex stainless steel. Duplex 2007 Int. Conf. Proc. Grado, Italy (2007).
7] A. MIAZZON, Large span bridges: the construction of steel plated box girders. An example: the Storebaelt East Bridge. Costruzioni Metalliche n.6, ACAI Servizi (2004).
8] S. CARAMELLI, P.CROCE, M.FROLI and L.SANPAOLESI, Misure ed interpretazioni dei carichi dinamici sui ponti. ECSC Project n. 7210-SA415 (F6.7/90).
9] S.J. MADDOX, The fatigue behaviour of trapezoidal stiffener to deck plate welds in orthotropic bridge decks. TRL Report No. SR 96
10] K. YAMADA, A. KONDO, H. AOKI and Y. KIKUCHI, Fatigue strength of field-welded rib joints of orthotropic steel decks. IIW doc. XIII-1282-88, Department of Civil Engineering, Nogoya University, Nogoya (1998).
11] J.R. CUNINGHAME, Steel bridge decks: fatigue performance of joints between longitudinal stiffeners. Report No. LR 1066, 1982.
12] L. BRISEGHELLA, E. MAIORANA and A. MIAZZON. Duplex stainless steel: an alternative for structural applications. Costruzioni Metalliche n.1, ACAI Servizi (2004).
13] A. MIAZZON, The Verrand viaduct in Courmayeur, an orthotropic deck bridge. Design, construction, assembly and launching. Costruzioni Metalliche n.1, ACAI Servizi (2005)
14] L. RAMPIN, A. MIAZZON and others, Fatigue design in steel bridges. XIX CTA Conf. Genua, Italy (2003).
15] B.JOHANSSON and A.OLSSON, Current design practice and research on stainless steel structures in Sweden. Jour. Const. Steel Res. 54, 3-29 (2000).
16] ASTM E 917-05. Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems.

ABSTRACT

APPLICAZIONE DELL'ACCIAIO INOSSIDABILE DUPLEX NELLA COSTRUZIONE DI PONTI SALDATI IN SITUAZIONI AMBIENTALI AGGRESSIVE

Parole chiave: acc.inox, corrosione, fatica, saldatura, selezione materiali

I costi di manutenzione sono una voce rilevante nel ciclo di vita delle infrastrutture metalliche, specialmente quando queste sono situate in ambienti particolarmente aggressivi, per esempio per la presenza di cloruri in elevata concentrazione. In ambiente marino del resto vengono tipicamente costruiti i più grandi ponti sospesi per traguardare luci sempre maggiori (Akashi Kaikyo in Giappone, Storebaelt East in Svezia): un'aspettativa di vita di oltre 100 anni è il parametro di progetto per tali infrastrutture. Per garantire ciò è necessario non solo proteggere le strutture metalliche con adeguati sistemi in fase di realizzazione (Tab. 1), ma anche programmare ispezioni e manutenzioni in maniera da mantenere l'opera in adeguate condizioni di sicurezza durante tutto il ciclo di vita.

L'utilizzo di acciai intrinsecamente resistenti alla corrosione è un altro modo per garantire l'adeguatezza agli standard di progetto, in quest'ottica l'utilizzo di acciai inossidabili austeno-ferritici (duplex), con la loro elevata resistenza alla corrosione unita all'alta resistenza meccanica, potrebbe costituire un notevole passo avanti verso la sicurezza e dunque l'aspettativa di vita in esercizio.

Tuttavia, benché le caratteristiche meccaniche di base degli acciai inossidabili duplex siano ben note, poco si conosce sul loro comportamento quando assemblati in componenti saldati di geometrie complesse, i.e. le lastre ortotrope (Fig. 3) largamente utilizzate negli impalcati di ponti di media e grandissima luce, soggetti ai carichi variabili del traffico. Componenti di questo tipo, sia per la loro complessità che per l'importanza strategica in termini di sicurezza, sono stati ampiamente testati in passato per gli acciaio tradizionali da costruzione (i.e. S355) e spesso richiedono tutt'ora un design assisted by testing nelle opere di nuova realizzazione.

Per colmare almeno parzialmente questo gap di conoscenza il Fondo di Ricerca per l'Acciaio ed il Carbone ha finanziato un progetto di ricerca ("Bridgeplex" RFS-CR-04040) sull'applicazione di acciaio duplex EN1.4462 alla costruzione di ponti in lastra ortotropa in ambienti aggressivi (i.e. classificabili C5 secondo EN ISO 12944). Il progetto prevede la realizzazione, anche in piena scala, ed il testing di componenti saldati caratteristici della tipologia a lastra ortotropa ma realizzati in acciaio duplex EN1.4462.

In questo articolo, oltre a presentare sommariamente le attività del progetto, ci si sofferma in particolare sull'analisi dei costi del ciclo di vita, svolta sulla base delle informazioni tecniche ottenute durante tutto il progetto. I risultati sono incoraggianti ma non decisivi, in quanto il costo del duplex è molto variabile ed ha subito proprio nel periodo del progetto un notevole incremento (+83%). La fattibilità dell'applicazione con gli stessi livelli di sicurezza e nelle stesse condizioni di esercizio del caso studio viadotto Verrand, è stata dimostrata da un punto di vista tecnico mediante le attività di realizzazione della carpenteria, da una parte, di testing sperimentale e simulazioni al calcolatore dei carichi di esercizio dall'altra. L'acciaio duplex ha mostrato di essere competitivo anche economicamente rispetto ad un acciaio da costruzione ad elevata resistenza (i.e. S460), in quanto si prevede un recupero dell'investimento iniziale a metà ciclo di vita (Fig. 7), risparmiando tra l'altro il costo sostenuto dall'utente dell'infrastruttura dovuto alle chiusure anche se parziali per manutenzioni straordinarie e realizzando comunque un'opera dal valore intrinseco superiore.