Stainless steel and profiling: a solution for the railway industry?

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Roll forming (profiling) is known as a versatile process to create long, often complex metallic shapes from strips and that in a continuous way. Due to its formability and work hardening behaviour, stainless steel exhibits an interesting potential to create such profiles. Moreover, its corrosion resistance makes it a durable and economical solution too. This paper discusses a case study about a profiled ("section rolled") design that replaces a 1.4571 (316Ti) welded solution for a long structural parts in a railway car body shell. Starting from the desired shape, a grade selection has been performed, prototypes have been characterised and the industrial product has been produced accordingly. An alternative stainless steel grade has been selected for this complex part because of its roll forming capability, high mechanical properties, fatigue and corrosion resistance. After all the tests done, corrosion and fatigue properties were adequate.

Keywords:
Railcar, railway, roll forming, profiling, section rolling, stainless steel, formability

INTRODUCTION

Roll forming is a continuous production process in which a long strip of metal is passed through a consecutive set of rolls, each performing an incremental part of the deformation. From this point of view, it allows to produce long and complex metallic shapes. Some industries such as building (window, door frames and structural parts), transportation (trucks, busses, railcars and highway infrastructure), ... frequently use roll formed products. Because of its advantages it helps customers to find economical solutions by e.g. avoiding welded assemblies. Complex parts with high dimensional accuracy can be produced at a high speed and with little handling. Because of its forming ability, stainless steel is a metal that is very suitable for roll forming [1]. Therefore stainless steels are profiled in a typical thickness range from 0.4 – 8 mm resulting in parts up to ~ 30 m length. Because of its ability to work harden, the profiles' strength will be enhanced during the cold forming [2].
A research was carried out to replace a 1.4571 (316Ti) welded solution for a 15-17 m long structural part by a stainless steel profile with a complex shape (figure 1) in a collaboration between Aperam (stainless steel producer), Voest Alpine – Sadef (profiler) and Alstom Transport (railway car body producer). The goal was to replace the welded solution by a complex profile in order to reduce weight, manufacturing cost (manual welding of the different parts together) and to integrate the different rail functionalities (such as mounting of equipment). This paper presents the problematic in terms of formability and properties of the final part.

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FIG. 1
(a) Previous and (b) new profile solution.
Soluzioni di profilo precedenti (a) e nuove (b).

INFLUENCE OF GRADE SELECTION

The goal was to select a grade out of the existing stainless steel families to produce the roll formed profile. It was assumed that this grade family could be profiled into the complex shape and still exhibits sufficient corrosion and fatigue resistance. So just by selecting a less alloyed grade (compared to the original solution, i.e. 1.4571-316Ti), this could lead to a cost reduction on raw material level. 1.4571 (316Ti) was selected in the original solution because of the fear that the corrosion resistance in the weld area was lower than that of the base material. In the profiled solution, the welding is avoided.
In a first step a 180° bending test with a the bending ratio r/t = 0, which is the ratio between the bend radius r and the thickness t, has been performed to reproduce as closely as possible the roll forming process, yet in a simple way. Within the selected family, different variants are available, these differences concern nickel and carbon content mainly. The prime objective was to

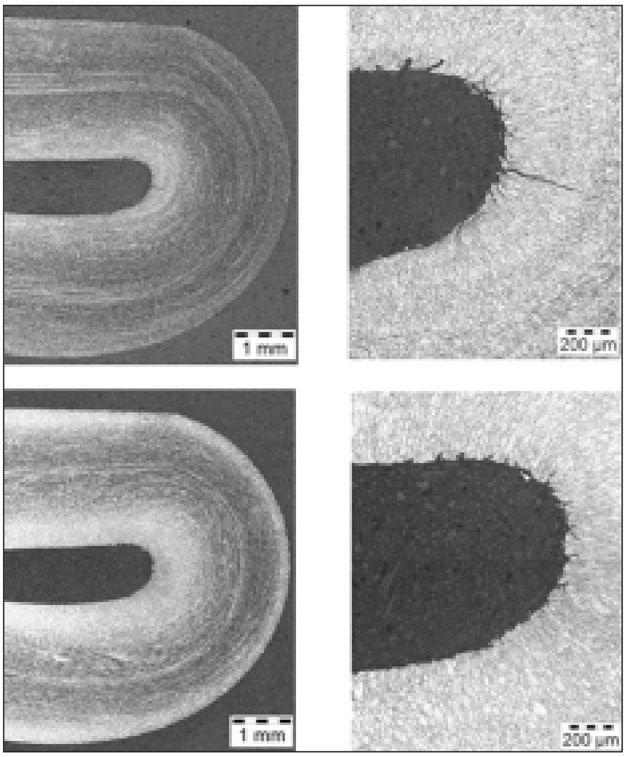


FIG. 2 ***Comparison of defects between different grades in the optimised profile configuration. The optimised grade (below) gives clearly a good result.***

Confronto dei difetti indotti fra diversi gradi di acciaio nella configurazione di profilo ottimizzata. Il grado ottimale (sotto) dà chiaramente un buon risultato.

compare the forming behaviour of these different grades and to determine the best candidate with regard to forming ability for this application. It is expected that Ni and C have an effect on the stability of the grade, which results in a complex equilibrium between increasing stretch formability (based on elongation) and on the other hand reducing ability to work harden.
Thickness also has a significant influence. This is directly related to the higher strain level which induces higher stresses. Based on these test results, one grade was selected to be the safest solution. It is well-known that a higher thickness induces more severe deformation conditions during bending. Yet roll forming involves a more complex deformation conditions than pure bending, the latter being considered as a worse case simulation. Therefore a comparative production run with the optimised roll forming parameters has been performed on different grades of the selected family. The goal was to compare the best possible alternative. One, which is more expensive and less standard and a other more standard variant. The results are compared in figure 2. The standard grade however shows much deeper cracks (upper one). A the end the right grade could be selected accordingly (lower one).

INFLUENCE OF PROFILING PARAMETERS

Significant influence of the profiling parameters has been observd: pressure, lubrification, speed, internal radius, ... A few of industrial trials were performed to come to an optimised condition. The different tests resulted in the good combination of tool pressure, lubrication level and optimisation of the geometry. This permitted to optimize the required level of quality needed for the application.

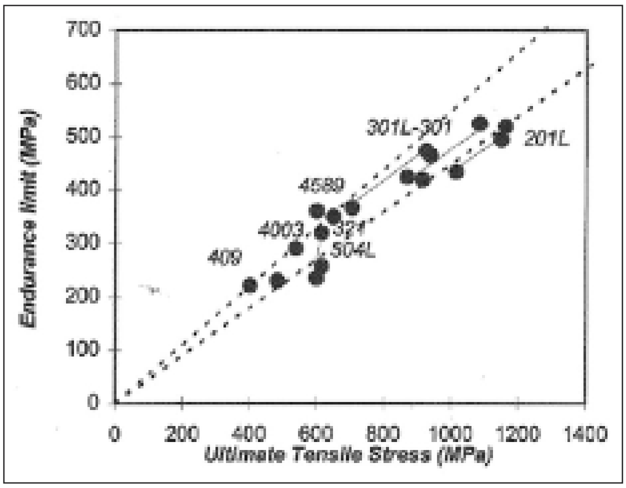


FIG. 3 ***Effect of mechanical properties on fatigue limit for different grades in the annealed condition a correlation is found between UTS and endurance limit [3].***

Effetto delle proprietà meccaniche sul limite di fatica per i diversi gradi nella condizione di ricotto; si è trovata una correlazione fra UTS e limite di resistenza alla fatica[3].

FATIGUE RESISTANCE

During its lifetime, the profile is subject to fatigue. From a theoretical point of view, several parameters have an influence on the fatigue resistance. There is a clear link between the yield or ultimate tensile stress and the endurance limit (figure 3). Because of the work hardening which occurs during the profiling, the ultimate tensile strength is increased, and as such also the endurance limit.
Besides the mechanical properties, the surface finish (1D, 2B, ...) has an influence on the fatigue behaviour too. This is due to the difference in roughness of the final product. Indeed, fatigue performance depends on the surface quality, and especially on Rt, the maximum roughness amplitude, since surface irregularities act as potential initiation sites for fatigue cracks (figure 3).

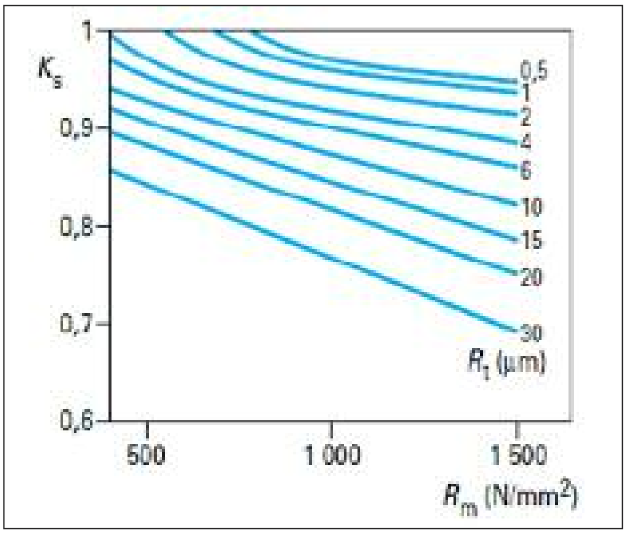
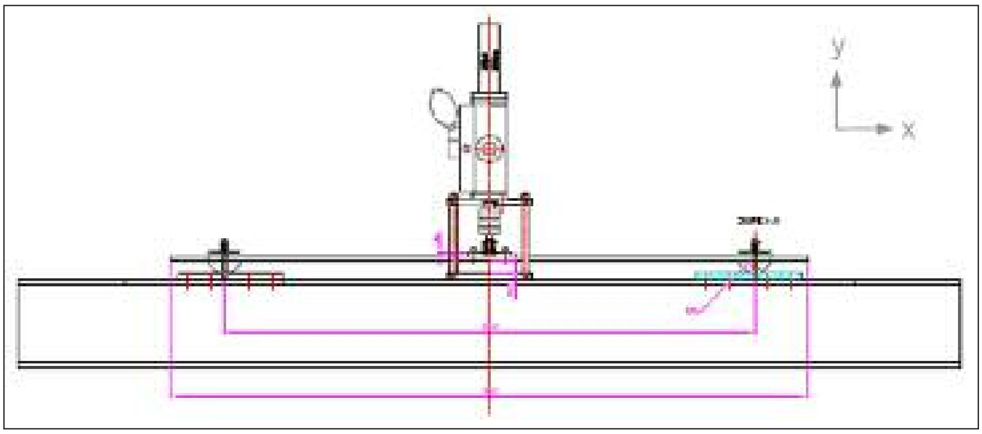


FIG. 4 ***Effect of surface roughness on the fatigue limit ratio K_S, defined as $\sigma_D/\sigma_{D,polished}$ [4].***

Effetto dello stato superficiale sul rapporto K_S del limite di fatica, definito come $\sigma_D/\sigma_{D,lucidato}$ [4].

FIG. 5
Bending fatigue test – scheme of the test.
Prova di fatica a flessione – schema della prova.



Also a 3 point bending (Figure 5) test has been carried out on a 3m long profile to assess the resistance to high cycle fatigue of such a part. The test was carried out controlling the deflection of the central part (cyclic vertical displacement). This was to simulate the real life behaviour of the part.
Periodic liquid penetrant inspections were performed to monitor crack formation. No crack was detected during the test. Finally, the in-service stress has been evaluated and compared to the theoretical fatigue resistance of the material in sheet form. The lifetime requirement did not seem to be critical for such application.

CORROSION RESISTANCE

Although the profile is completely covered in the present configuration, Alstom Transport wants to have the possibility to use it uncovered (in contact with rain). In that case, it remains visible and no evidence of corrosion (even superficial) would be acceptable. Even if the corrosion is generally accepted for rail car applications [5], the forming process increases the roughness in the folded area. The roughness of the folded areas is more than that of the non-deformed material. Therefore a salt spray test has been performed to compare the corrosion resistance between the base material and the formed part. Different samples (bended and profiled) have been exposed to salt spray trial. The results from this test have shown no degradation in the corrosion resistance.

CONCLUSION

By combining an optimised profiling process and selecting a correct grade, a solution was developed for a structural roll formed profile. The optimisation permits the selection of a grade that reaches the required quality level. The final part has a corrosion and fatigue resistance that makes the part fit for use. As such, a more economical solution is found through the roll forming process: a welding step is avoided and some weight was saved.

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Abstract

Profilatura e acciaio inossidabile: una soluzione per il settore ferroviario?

Parole chiave: acciaio - automotive - laminazione

La profilatura è un processo noto per la sua versatilità nella produzione di forme metalliche lunghe e spesso complesse da nastri e in modo continuo. Grazie alla sua lavorabilità e al comportamento all' incrudimento, l' acciaio inossidabile presenta un interessante materiale potenziale per la creazione di tali profili. Inoltre, la sua resistenza alla corrosione lo rende anche una soluzione duratura ed economica. Questo articolo presenta un caso di studio relativo al progetto di un profilo laminato ("section rolled") che sostituisce una soluzione saldata 1.4571 (316Ti) di parti strutturali lunghe della una scocca di un vagone ferroviario. Partendo dalla forma desiderata, è stata effettuata una selezione del tipo di acciaio, sono stati caratterizzati prototipi e di conseguenza è stato realizzato il prodotto industriale. Per questo complesso particolare è stato selezionato un tipo acciaio inossidabile alternativo, per le sue particolari caratteristiche verso la laminazione, le elevate proprietà meccaniche, la resistenza alla fatica e alla corrosione. Al termine di tutte le prove effettuate, resistenza alla corrosione e fatica si sono rivelate adeguate.