THE APPLICATION OF HIGH-ALLOYED STEEL IN VEHICLE STRUCTURES WELDING SOLUTIONS

Horst Herold; Jörg Pieschel - Otto-von-Guericke-University Magdeburg, Germany
Sven Jüttner - Volkswagen AG

ABSTRACT

The application of high-strength steels in vehicle structures is an obvious choice in view of increased vehicle safety requirements and the trend towards harmonising lightweight engineering and recycling in order to conserve natural resources. As a rule, however, the weldability of such materials is not always guaranteed.
A good alternative is the use of high-alloyed steels, such as the austenitic CrMnNi steel with the material number 1.4376. Due to its very good mechanical strength properties, this material has great potential for lightweight vehicle design. Furthermore, the reduced nickel content and the good corrosion resistance also make this material interesting from an economic point of view.
If tests of the joining ability of this steel show that it has unlimited weldability and unproblematic application in vehicle structures, this material would be recommended for use in automotive engineering.

KEYWORDS

High-alloyed steel, Vehicle structures, Body designs, Welding, Corrosion resistance, Operating loads

INTRODUCTION

The steel unibody design has for years been the dominant method of producing vehicle bodies in the automotive industry.
Basically, the designs of modern cars can be divided into three main groups:

- Monocoque
- Unibody
- Spaceframe

There also exist mixed forms of these designs, and among these the mixture unibody / spaceframe is now widely used. [1]

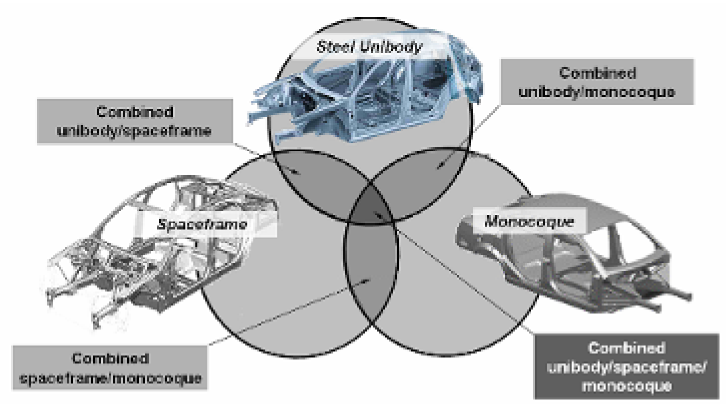

Fig. 1: Classification of body designs

1. VEHICLE BODY DESIGN TRENDS

The decisive disadvantages of the unibody design are the increasing investment costs for press shops combined with the trend towards greater model variety and shorter product life cycles.
Recently, design engineers have been considering alternative vehicle concepts to an increasing extent. For example, as a result of experience with concept cars and niche vehicles, the spaceframe design is now gaining greater importance in series application, Figure 2.

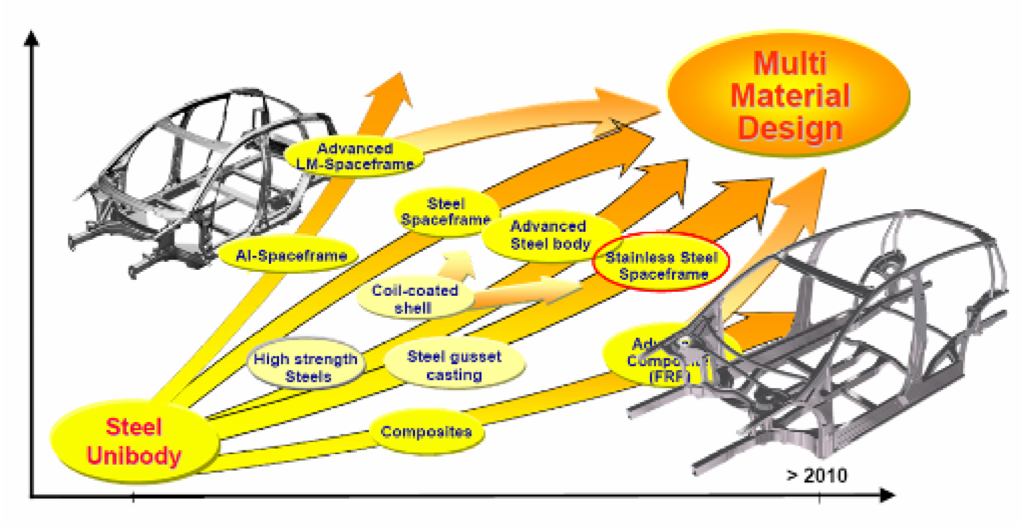

Fig. 2: Development trends in vehicle design [2]

In recent years, the development of the spaceframe design also led to intensive research into the possibility of substituting steel with, for example, aluminium or even magnesium.

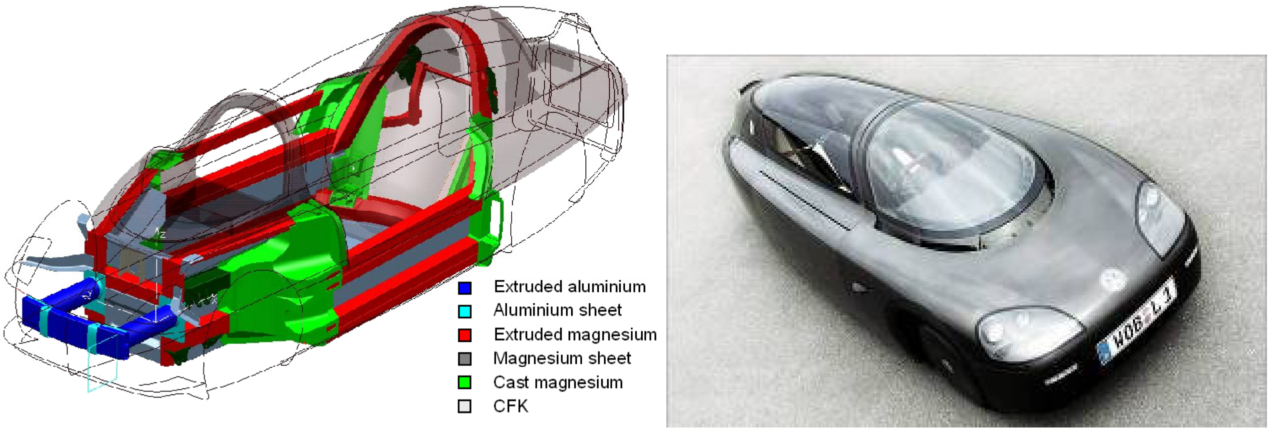

Fig. 3: Spaceframe of the 1-litre car

Under the term “Multi-Material Design”, engineers are now considering a growing number of new body concepts that are characterised by a mixture of materials, in contrast to modern steel or aluminium mono designs. The main idea behind these new concepts is to use the right material in the right place. Volkswagen has demonstrated the lightweight design potential of these concepts by making the world’s first “1 litre car” (i.e. with a fuel consumption of just 1 litre per 100 km) with a body that was implemented mainly by the consistent use of multi-material design comprising a magnesium spaceframe and carbon fibre reinforced plastic structural parts.

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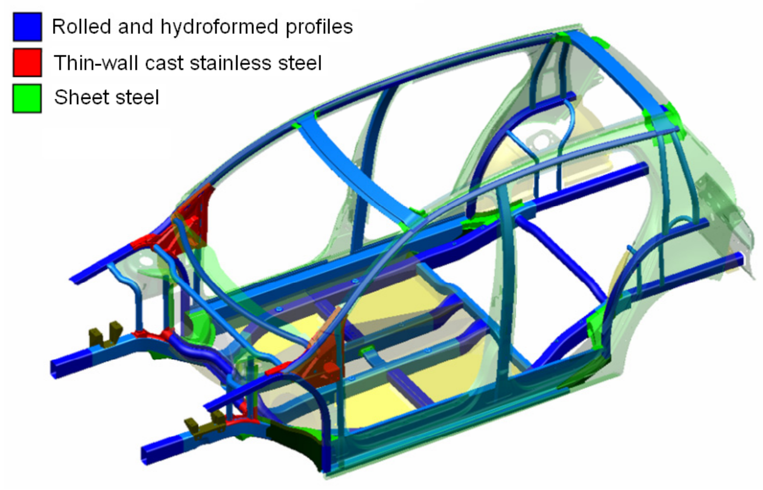

Fig. 4: Stainless steel spaceframe [1]

The methods of optimising a steel design include the use of high-strength steel grades and further developed manufacturing techniques (tailored blanks, hydroforming, etc.). More recent approaches include new processing technologies, alternative structural designs and the use of stainless steels.
Even with steel, the use of a spaceframe made of closed profiles for the load-bearing structure of the vehicle body allows a force flow-optimised design in addition to a more efficient use of space (due to the elimination of flanges) and the integration of components. Furthermore, the use of high-strength, non-corroding stainless steel also offers the possibility of minimising the expenditure for protecting the body-in-white against corrosion.
A suitable combination with an outer skin made, for example, of light metal or plastic would also offer a weight-saving potential [3].

2. JOINING SYSTEMS FOR BODY DESIGN

The acceptance of new materials and designs will depend in particular on the availability of low-cost and process-reliable manufacturing technologies. The key to achieving this will be, among other things, the use of joining techniques that are appropriate to the design and the material and which meet the requirements of a joining process for automotive body manufacture.

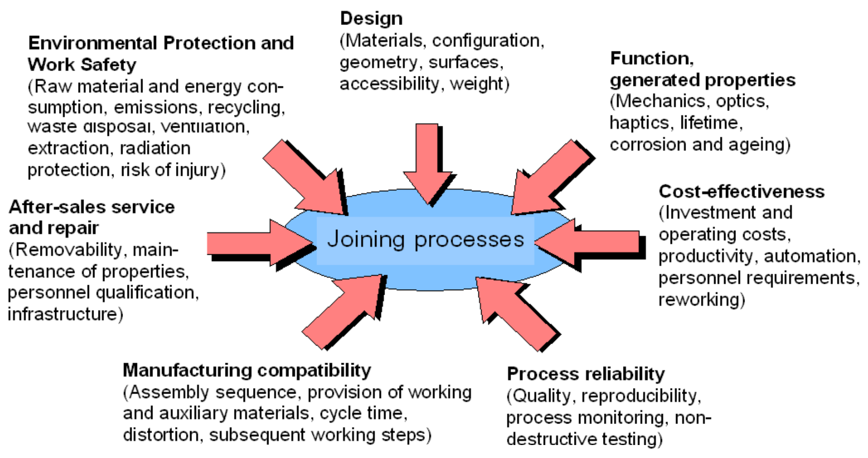

Fig. 5: Requirements to be met by joining processes [3]

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In addition to criteria such as cost-effectiveness, manufacturing compatibility, process reliability, environmental friendliness and work safety, the decisive factor in selecting a joining process is in particular the fact that the required mechanical properties of the joint are guaranteed over the whole lifetime of the vehicle. [3]
The following figure (Figure 6) shows the main operating loads on a vehicle structure.

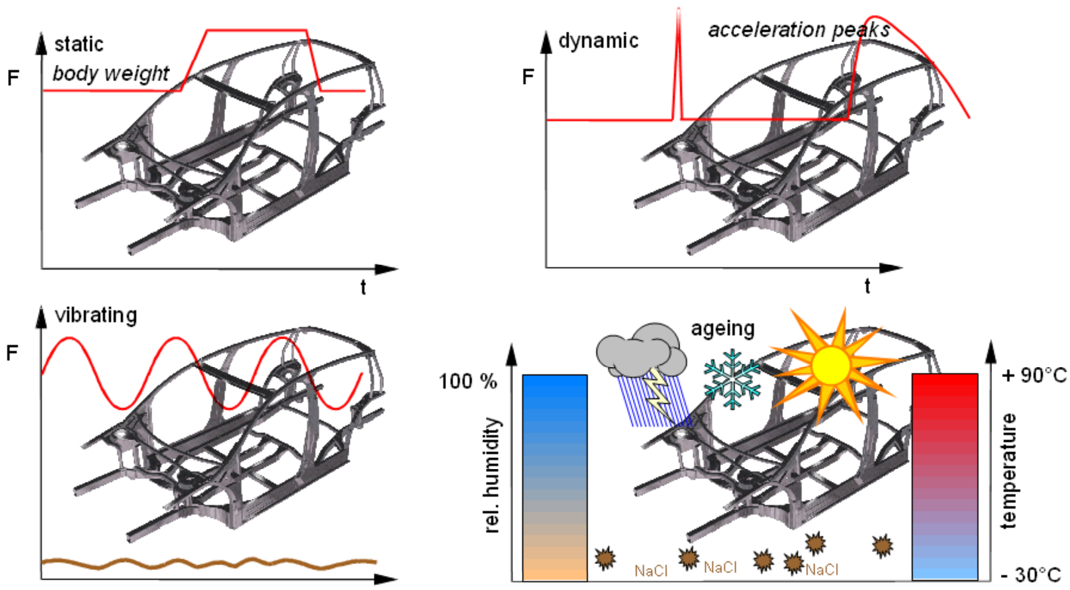

Fig. 6: Operating loads on the vehicle structure

3. SELECTING THE STRUCTURAL MATERIAL

The following mechanical properties are essential if the vehicle body and its joints are to meet the requirements:

- High rigidity in order to guarantee functionality and ride comfort.
- High vibration strength in order to bear the operating loads safely.
- High fatigue strength in order to guarantee maximum passive occupant protection in the event of a crash.

For the manufacture of an experimental stainless steel spaceframe structure, a high-alloyed austenitic steel with a particularly low nickel content (Table 1) and a sheet thickness of t=1.0 mm was chosen. The low nickel content makes the steel very cost-effective.
According to information provided by the steel manufacturer [4], the material has good weldability. Due to the unstable austenitic structure, the material has a work hardening tendency, which means that considerable increases in strength can be achieved even with low degrees of deformation. The strong work hardening effect also results in very high energy absorption in the event of a crash.

Table 1: Guideline values for the chemical composition and mechanical properties of CrMnNi steel [4]

Elements by % weight					
Fe	C	Cr	Mn	Ni	N
Residual	≤ 0,1	17,0-20,5	5,0-9,0	≤ 3,5	≤ 0,30

$R_{p0,2}$ [N/mm²]	R_m [N/mm²]	A_{80} [%]
400-480	600-900	≥ 40

4. CONSTRUCTION OF AN EXPERIMENTAL BODY

In order to subject the selected material used in a structural application to a road test, it was necessary to build a drivable experimental spaceframe for systematic tests using thermal joining (welding).

Since no consumable welding material of the same type was available for welding 1.4376, solid wire electrodes SG-X15CrNiMn18-8 (1.4370) and SG-X2CrNi19-9 (1.4316) with a diameter of 1.0 mm were used as welding consumables.

Table 2: The welding consumables used

Designation	Elements by % weight									
	Fe	C	Cu	Cr	Mn	Al	Ni	Zn	N	Si
SG-X15CrNiMn18-8	Residual	0,08	-	19,0	7,0	-	8,5	-	-	0,8
SG-X2CrNi19-9	Residual	0,03	-	20,0	2,0	-	10,0	-	-	0,9
SG-CuAl5Mn1Ni1	0,8-1,2	-	Rest	-	1,0	5,1	1,0	-	-	-

Based on previous experience of using these welding consumables and following the recommendations of the manufacturers, a mixture of 97.5% Ar / 2.5% CO_2 (approx. 15 l/min) was used as the shielding gas for the MAGp welding process. Argon 4.6 was used as the root shielding gas.

In order to guarantee feasibility for a subsequent production scenario, it was important to implement the MAGp welding primarily as automated robot welding. Some parts of the 1.4376 were also joined by MIGp soldering in order to minimise the energy input. A copper-based solder (Table 2) was used for this purpose. WIG welding was also used to a limited extent. Resistance spot welding was also performed on joints between the profiles and sheet metal.

The construction of the body can be summarised in the following five points:

1. Performance of preliminary tests to secure the technology and determine the joining parameters.
2. Design and building of suitable welding equipment.
3. Assembly of the structure in the clamping buck.
4. MIG welding of the frame structure.
5. Local aftertreatment of selected weld seams to remove temper colour.

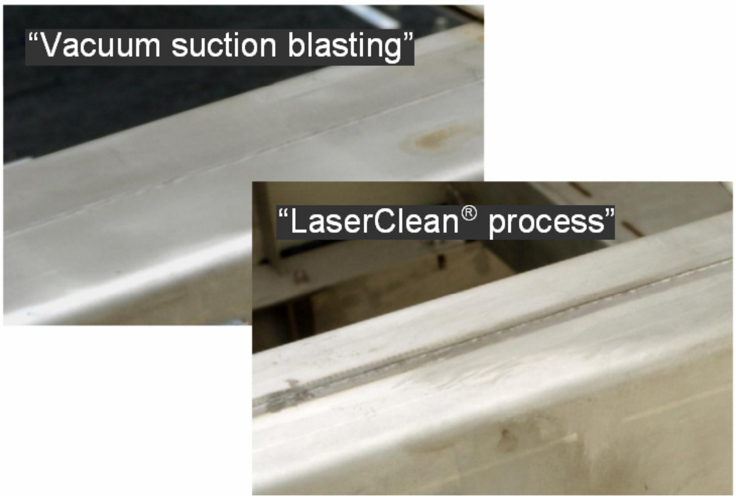

Fig. 7: Blasted and laser-treated profiles

Various aftertreatment processes were performed on the weld seams:

- Pickling
- Electrolytic polishing
- Brushing
- Blasting with glass balls
- Pulsed laser material removal

The profiles were closed by longitudinal weld seams using both laser welding and plasma welding. After welding, aftertreatment was performed locally, Figure 7.

During the manufacture of the profiles and the joining of the structure, the weld seam root was formed with the aid of suitable devices inside the profiles, Figure 8. Argon 4.6 was used as the forming gas. In order to provide different versions for examination, some individual seams were left untreated. Other seams were subjected to various aftertreatment processes, Figure 9.

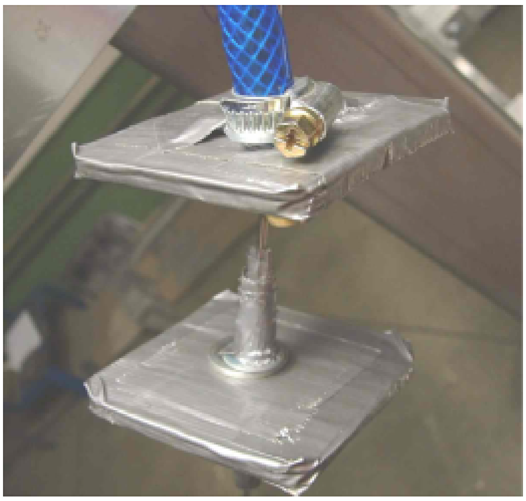

Fig. 8: Example of a forming device

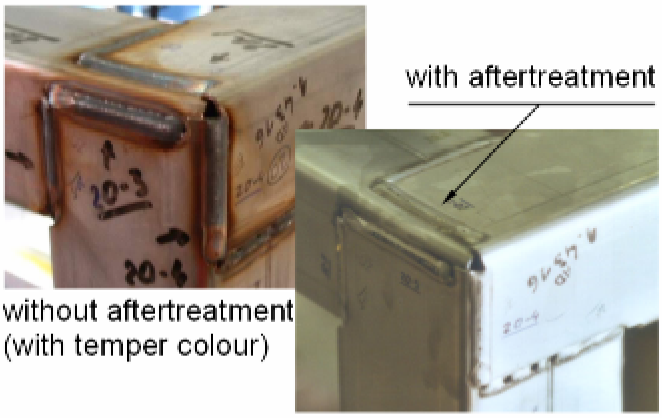

Fig. 9: Example: Welded profile joint with and without local electrolytic cleaning

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5. CORROSION TESTING IN ENDURANCE DRIVING TEST

The endurance test simulates the loads applied to the vehicle over a period of several years, but takes only a few months. The test is used to provoke both surface corrosion and local material removal, such as rust perforation or peeling.
In the endurance test, the structure was exposed to a real-life load collective for passenger cars as shown in Figure 6.
This made it possible to represent in particular the progression of corrosion in combination with vibrating mechanical loads on the structure in a strongly time-compressed manner.

The unprotected structure was subjected to the following cyclical loads:
- Driving over rough surfaces ("torture tracks")
- Driving over gravel track sections and through mud and salt water
- Stationary periods with heat and salt water spray
- Stationary periods with cold and salt water spray
- Dry phases

The evaluation of the corrosion image was performed on the test spaceframe in accordance with DIN 53230 on the basis of a relative evaluation scale that describes the degree of corrosion on five levels. Level 5 corresponds to severe rust formation.
Figure 10 shows the graph of the corrosion of all welded and soldered joints over the test period.

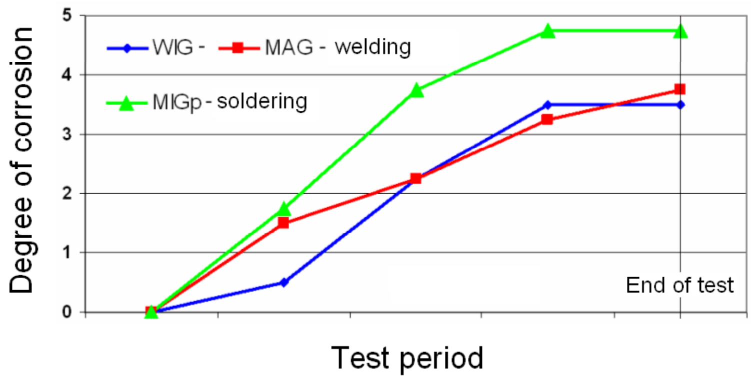

Fig. 10: Comparison of corrosion depending on the joining process

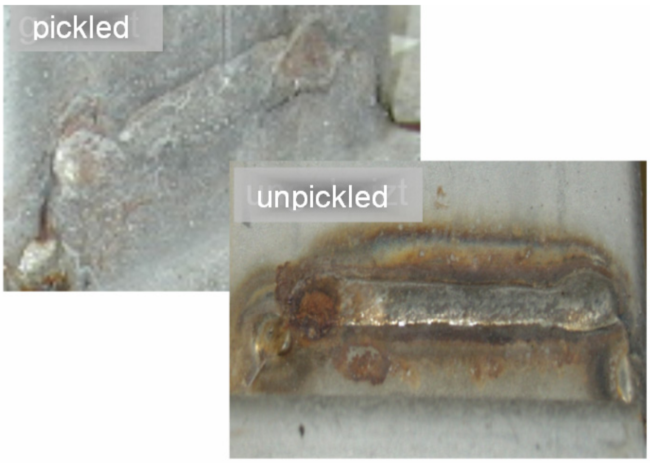

Fig. 11: MAGp joints at the end of the test

Figure 11 shows comparable MAG joints from the structure in a treated and untreated state at the end of the endurance test. Whereas the treated weld seam shows hardly any corrosion, the untreated seam has obvious surface corrosion.
Macroscopic examinations of the cross-sections of these joints reveal no noticeable corrosion, Figure 12.

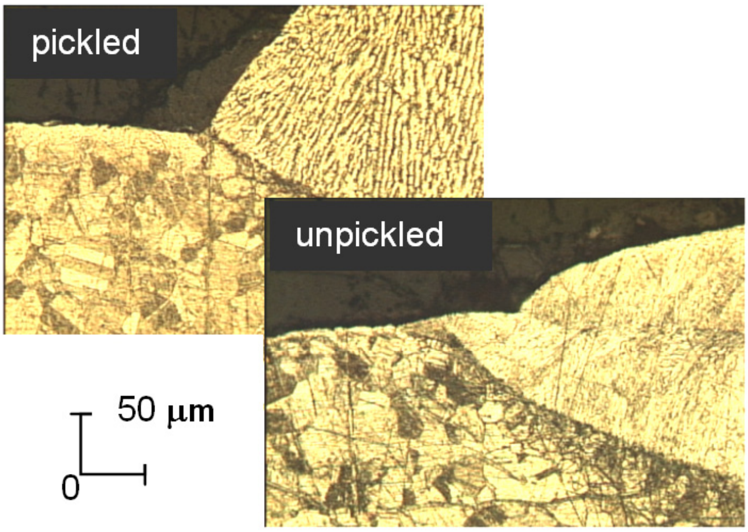

Fig. 12: Comparison of MAGp weld seams

In none of the welded joints was mechanical failure observed at the end of the endurance test. In contrast, the soldered joints had severe external corrosion combined with infiltration and cracks. Severe corrosion was observed in particular on the seam of the joints in the transition area from the solder to the base material, caused by the electrochemical potential between the copper-based solder and the base material. The cross-sections provide further evidence of the severe corrosion and show how entire grains become detached, Figure 13.

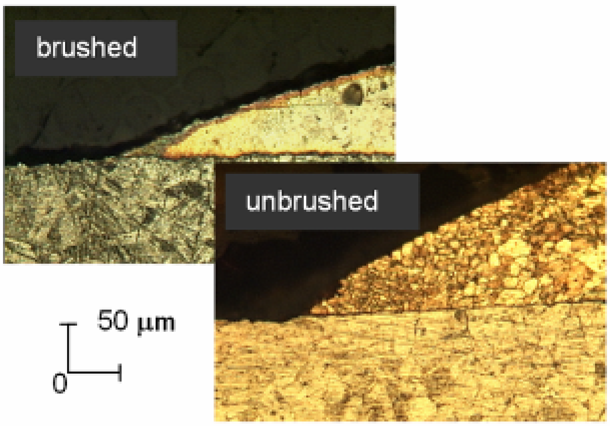

Fig. 13: Corrosion on MIG soldered joints

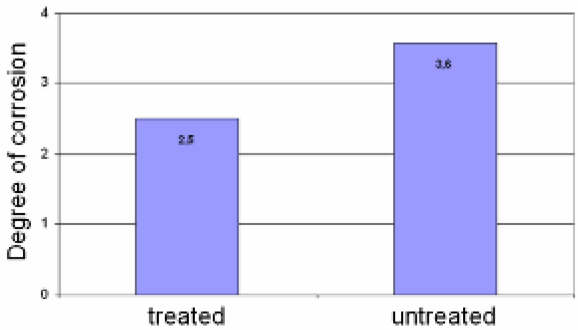

Fig. 14: Influence of aftertreatment on the corrosion of the welded joints

Furthermore, the base material has cracks in the area of the soldered joints. All the soldered joints already failed half way through the test period. This was shown by continuous cracks in the solder material in the direction of the seam.
Figure 14 describes the corrosion behaviour of the joints of the whole structure, considering all joint variants and the use of aftertreatment.

6. SIGNIFICANCE OF THE WELDING METHOD

The following challenges were identified in manufacturing the frame structure of austenitic CrMnNi steel:

- Special manufacturing requirements due to the material
- Problem of distortion
- Problem of corrosion

The 1.4376 steel used here has a strong tendency to work hardening. Processing with material removal should be avoided for large production volumes. Sheets, profiles and components should if possible be cut by laser cutting.

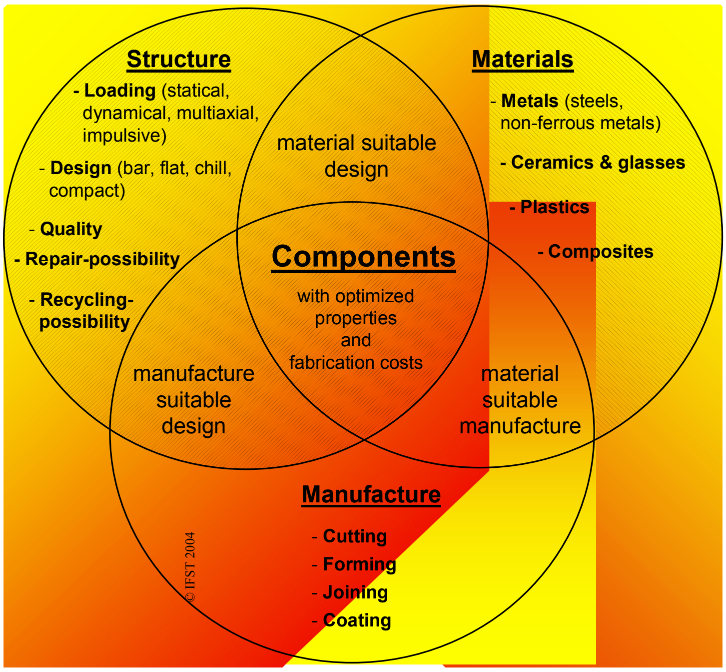

Fig. 15: Joining technological correlation between structure, material and fabrication

Due to the austenitic structure of the material, relatively severe welding distortion is to be expected. Attention should therefore be paid to minimising heat input into the material during welding. Constructive measures and a suitable order of the welding actions can minimise but not rule out distortion. The design of the clamping buck has a decisive influence on distortion. When planning and building complex spaceframe structures made of steels such as the 1.4376 steel used in this case, the design, process, manufacturing sequence and equipment must be precisely and simultaneously coordinated.
With regard to the strength of the joint and especially its corrosion resistance, welding consumables must be at least equally alloyed or higher alloyed than the base material in accordance with their alloy composition. For soldered joints, consideration must be paid to the fact that the strength of the joint is reduced and that it is no longer resistant to corrosion.
The corrosion tests showed that the most important problem in using such a structure is gap corrosion. Constructional measures should be taken to avoid gaps, or they should be sealed.
Resistance spot welding combined with a sealing material suitable for spot welding provided very good results for joining profiles and sheets.

7. SUMMARY

The usual processes for CrNi stainless steels can be used for the material 1.4376.
With regard to corrosion behaviour, gap corrosion should be seen as the most important aspect. Gaps must be avoided or protected.
Joints should be welded as cleanly as possible, since end craters and joining defects are sources of corrosion. The use of copper-based solders is not advisable.
In order to improve corrosion resistance, temper colour should be avoided or removed.

The substitution of nickel by manganese as an alloy element means that material costs are relatively low. The high yield point and the very good fatigue strength make this material interesting for use in vehicle structures.

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