STRENX®
PERFORMANCE STEEL

TRAILER DESIGN GUIDELINE
STRENX: THE FASTEST ROUTE TO EFFICIENT TRANSPORT.

SSAB

Introduction

Steel is the most common engineering material in the world. In comparison with other materials steel is cheap to produce and can be found in a wide range of grades suitable for a huge field of applications and production methods. Steel is also the most recycled material in the world; each year more steel is recycled than aluminum, paper, glass and plastic put together. Since the first steel reference in history, coming from a 4,000 years old archeological site in Turkey, great efforts have been put into developing steel into the Advanced High Strength Steels (AHSS) we benefit from today.

Road transport vehicles, like trucks and trailers, can significantly benefit from improvements in both design and production methods. Material selection is strongly connected to these aspects, and affects the performance and the cost of these vehicles. The use of AHSS allows lightweight solutions to be developed, which directly translates into financial savings and less CO_2 emissions.

AHSS is a natural choice for many companies looking to improve their product and to be more competitive. Successful companies using AHSS take the opportunity to be at the forefront with respect to material, design and process development, but still benefit from the knowledge and the experience built up over the years of using conventional steel. By introducing AHSS, these companies are acquiring new knowledge to be applied in the design and fabrication of their products.

At SSAB, we are always focused on supporting our customers to truly utilize the benefits of our advanced high strength steels. By implementing AHSS from SSAB, our customers not only get high quality steel but also a relationship where we share knowledge. Our customers know their products; we support our customers in selecting and utilizing the right steel grade for both design and production.

If you are in the trailer business and care about higher payload, less maintenance, fuel savings and increased product life, and if you want a smoother production flow, while still being environmentally responsible, then you will enjoy reading this document.

ECONOMICAL AND ENVIRONMENTAL ASPECTS OF THE USE OF AHSS IN THE TRAILER INDUSTRY

Using advanced high strength steel (AHSS) in developing lighter and stronger trailers is proven to have a big impact on the economical performance of the vehicle. It is well known that both trailer manufacturers and transport operators can gain part of the financial benefits, but the advantages in terms of lower CO_2-emissions should also be noticed.

BENEFITS FOR THE TRAILER MANUFACTURER

When looking into the financial benefits for the trailer manufacturer it is important to take all aspects affecting the overall production economy into account. Simply comparing price level per ton for different steel grades does not give a true picture of the manufacturing cost level. Reducing the sheet thickness will in most cases give a substantial cost reduction in both processing of the material and material cost. Even if the price per ton is higher for AHSS, less steel is consumed due to the weight reduction. Using thinner gauges in the workshop allows the cost for cutting, bending and welding to be reduced. Laser cutting in high strength steel is no different from cutting in mild steel and the producer will decrease the

cutting time due to the thinner gauge. Welding in thinner material gives, in most cases, the largest cost reduction due to the reduction of consumables and the opportunity to increase the welding speed. Introducing AHSS with good bendability may also allow the number of welds to be reduced. Bending of profiles in AHSS generally does not require greater force than a profile in a thicker gauge made from conventional steel. However, the spring-back of AHSS is greater compared to conventional steel and needs to be compensated for in the process.

To give a better insight into these issues a comparison of the production costs of a traditional, flatbed trailer chassis and a lightweight solution manufactured from AHSS is performed. The traditional trailer chassis included in this study is manufactured from hot-rolled standardized I-beams, which are cut and welded back together in the goose-neck region in order to produce the transition in height of the main beams. The cross-members consist of bent profiles welded to the longitudinal beams and there are also some side-wing profiles to support the floor. The side rail profiles are manufactured from standardized U-beams. All parts are produced from a S355-steel grade. In the lightweight solution the hot-rolled

I-beam has been replaced by a laser-cut and welded longitudinal I-beam manufactured from AHSS. Upgrading the traditional chassis by introducing AHSS allows the thickness of all major structural parts to be reduced and the weight of the chassis is thereby reduced by about 1,500 kg.

In addition to the weight reduction a 30 % production cost reduction can be observed, Figure 1. Cost has been decreased for both cutting and welding operations, but also for the material. In this case a slight increase of the bending cost can be observed. New profile cross-sections have been introduced, due to design issues, which require more bending operations. A 30 % cost reduction give obvious benefits for the producer and combined with a more attractive lightweight trailer great market advantages can be expected. It is also interesting to notice that this study was performed on an existing chassis where most structural parts consisted of hot-rolled profiles. If the existing traditional chassis would have been produced from welded beams even greater cost savings could have been achieved.

BENEFITS FOR THE LOGISTIC OPERATOR

A lighter and stronger trailer also has a direct and obvious benefit for the logistics operator, since the maximum weight of the vehicle is limited by law. A lighter configuration allows the payload to be increased on every trip and in many cases less fuel consumption can also be observed. The amount of fuel savings can be estimated in a conservative way to about 0.55 l/100 km per 1,000 kg of weight reduction. This directly affects the operating figures of any logistics company. Depending on the type of vehicle and the upgrading philosophy, the total weight can generally be reduced by 500 to 2,000 kg by introducing AHSS. By selecting the most suitable AHSS grades for the application, the costs associated with maintenance can also be reduced. Combining high strength with abrasion or weather resistance can improve the resistance to the tough demands on the performance of these vehicles.

ENVIRONMENTAL SAVINGS

In addition to the financial benefits, a lighter vehicle will reduce the environmental impact by saving primary energy resources and reduce greenhouse gas emissions.

In a life cycle assessment of a vehicle, different phases are often analyzed. When an upgraded trailer is compared to an original design in conventional steel, the influence of steel production and the service life is dominating. The latter often counts for 90 % of the total environmental savings for vehicles.

In analyzing the service life in the case of volume limited cargo the energy balance of the vehicle is considered. The basic energy consumption of road vehicles depends on several resistance factors that the vehicle has to overcome during its operation. Figure 2.

FIGURE 1   Comparison of production cost of conventional and lightweight trailer chassis including material cost.

WELDING
BENDING
CUTTING
MATERIAL COST

Using thinner material gives cost reductions in both welding and cutting operations and since less steel is consumed the material cost will also be reduced.
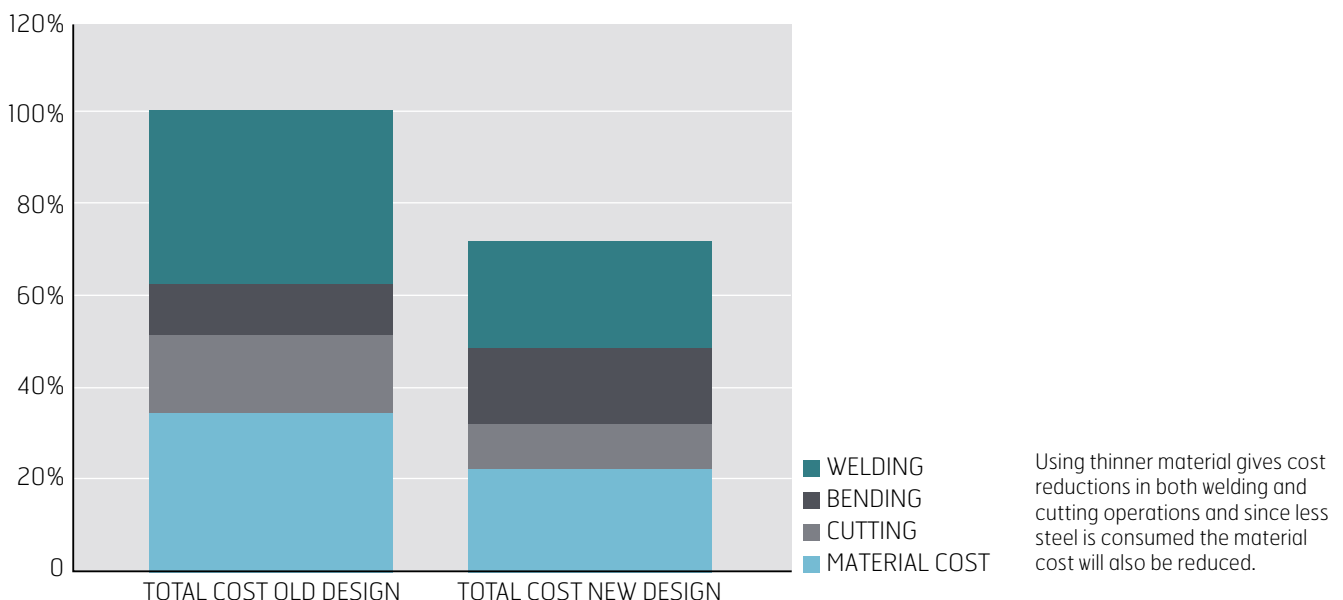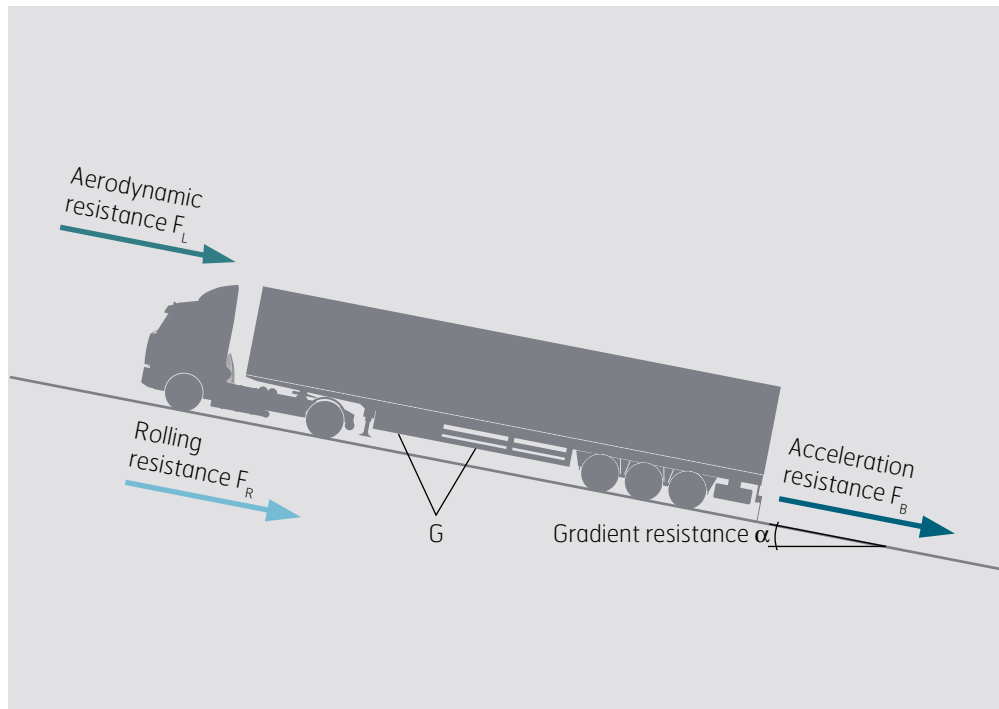
FIGURE 2 Overview of the resistance factors affecting the fuel consumption of any road vehicle.

F = Total resistance
ρ = Density of atmosphere
c_w = Aerodynamic resistance coefficient
A = Front area
v = Speed
k_r = Rolling resistance coefficient
m = Mass
α = Gradient angle
k_m = Acceleration resistance coefficient
a = Acceleration

$$F_{wi} = F_R + F_L + F_{St} + F_B$$

$$F_L = \frac{\rho}{2} \bullet c_w \bullet A \bullet v_x^2$$

$$F_R = k_R \bullet m \bullet g \bullet \cos \alpha$$

$$F_{St} = m \bullet g \bullet \sin \alpha$$

$$G = m \bullet g$$

$$F_B = k_m \bullet m \bullet a_x$$

With the exception of aerodynamic resistance, all resistance factors are linearly dependent of the mass. The aerodynamic resistance however, depends on the dimensions of the vehicle and the speed. Therefore, besides the mass, speed, acceleration and the gradient (hilly or flat) also affect the energy consumption. These factors are highly dependent on the driving situation and driving behaviour. With the same driving situation assumed, the correlation between energy consumption and vehicle weight is linear, and the energy saving corresponding to a specific weight saving is independent of the absolute weight of the vehicle.

Fast vehicles with a steady speed will therefore have a high aerodynamic resistance and low acceleration resistance and thus moderate specific energy savings by weight reduction. Consequently slow vehicles with frequent stops and accelerations will have high energy savings by weight reduction.

SEMI-TRAILERS

Large semi-trailers are the dominant modes of road transport in Europe as well as in the U.S. and accounts for a significant proportion of the fuel used in the transport sector. Either direct or indirect savings can be achieved by weight reduction. If the cargo is limited by volume, a lighter vehicle uses less energy for hauling, and if the cargo is limited by weight, additional cargo can be transported.

VOLUME LIMITED CARGO

In this case the gain in fuel consumption following a weight reduction is, as mentioned, heavily dependent of the driving situation which can be seen from the figures presented in Table 1, which shows typical values of fuel consumption for semi-trailers in different driving situations.

If we consider a 40 tonnes semi-trailer with a tipper body we can exemplify the influence of weight reduction on the environmental emissions and primary energy resources. We assume volume limited cargo and that these types of vehicles mainly drive on motorways and rural main roads. A specific fuel saving of 0.055 litre/100 km for 100 kg weight reduction is a conservative estimate. For the life cycle assessment (LCA), the total life for the trailer is set to 1.2 million km.

WEIGHT LIMITED CARGO

For weight limited cargo, the weight reduction of the vehicle permits higher payload to be carried and thus less vehicle-km are needed to transport a certain amount of goods. Energy savings for weight limited cargo are therefore higher than energy savings for volume limited cargo. As an example the savings in fuel consumption and CO_2-emissions for a light-weight tipper-trailer is calculated. The weight of the vehicle has been reduced by the use of AHSS, which has increased the payload by 1,839 kg, Table 2. With a life of 1.2 million km, 2,210,000 ton km transport performance can be saved during the life-time of the tipper-trailer; which is equivalent to 76,550 vehicle-km of fully loaded vehicles. If a fuel consumption of 40 l/100 km is assumed, this means a life cycle saving of 30,620 litre of diesel fuel, 81.4 ton saving of CO_2-emissions and 316 MWh primary energy savings per vehicle.

TABLE 1 Fuel consumption of typical semi-trailers in different driving situations and specific gain in fuel consumption achieved by weight reduction of the vehicles.

Load factor	Total weight (tonnes)	Motorway (litre/100 km)		Rural main road (litre/100 km)		Urban roads (litre/100 km)	
		Gabi[1]	NTM[2]	Gabi[1]	NTM[2]	Gabi[1]	NTM[2]
Empty (0 %)	14	23.6	22.6	22.7	23.0	35.4	28.8
Fully loaded (100 %)	40	37.8	36.0	41.4	39.6	64.4	50.4
Specific gain in FC of a weight reduction, (litre/(100 km*100 kg WR)).		0.052	0.049	0.069	0.061	0.107	0.080

1) Gabi LCA software and data base PE International, Leifelden-Echterdingen, Germany.
2) NTM Environmental data for international Cargo Road Transport Europe, Preliminary, Working document subject to updates, version 2009-12-22 Network for transport and the Environment, NTM, Sweden.

TABLE 2 Example of upgrading of a semi-trailer with a tipper body.

Weight and weight reduction due to upgrading from Strenx 355 MC to Strenx 700 MC									
Detail	Original [kg]	Upgraded [kg]	WR [kg]	WR [%]	R-CO$_2$ Steel prod [kg]	R-FC [l/100km]	R-CO$_2$ Service [kg/100km]	R-CO$_2$ Service life 1.2x106 km [kg]	R-Energy Service life 1.2x106 km [kWh]
Trailer chassis	1,109	676	433	39.0					
Additional chassis parts	400	344	56	14.0					
Axles, wheels, brakes, electro etc.	4,000	4,000	0	0					
Total semi-trailer*	5,509	5,020	489	8.9	710	0.27	0.72	9290	36,570
Tipper body weight	6,500	5,150	1,350	20.8					
Total semi-trailer tipper empty*	12,009	10,170	1,839	15.3	3,200	1.01	2.69	32,550	140,000
Pay load	26,991	28,830	+1,839	+6.8					
Total semi-trailer tipper fully loaded**	39,000	39,000	-	-	3,200	0	0	84,650	330,730

WR= weight reduction, R-CO$_2$=reduction in CO$_2$, R-FC= reduction in fuel consumption, R-Energy= reduction in primary energy consumption.

 * Environmental figures refer to volume limited cargo.
** Environmental figures refer to weight limited cargo with a load factor of 100 %.

DESIGN

Trailer designs are often a result of experience and knowledge achieved over the years by the producing companies, and the know-how of the end users. Good solutions are in general also applicable for lightweight vehicles produced in high strength steels. However, advanced high strength steel, (AHSS) enables new solutions, but may also call for design changes in order to utilize the higher strength.

A common trailer chassis consists of two longitudinal main beams manufactured from either standardized hot rolled profiles or welded I-beams and a number of cross-member profiles. For the cross-members, solutions with open profiles, tubes or box-section profiles can be found. Depending on the type of trailer, floor members and different support profiles can also be attached to the chassis. The king-pin region of the trailer usually consists of a king-pin plate and some reinforcement profiles.

The upgrading potential of a trailer chassis is generally not only limited by static load carrying capacity, but even more so by fatigue and stability issues. Therefore, finding a solution with matching load carrying capacity to the existing design serves as a good starting point, but in order to have a vehicle with matching or improved performance it is essential to address these other technical aspects as well. It is important to notice that poor design or production quality rapidly reduces the upgrading potential.

For a trailer chassis manufactured from mild steel, the dimensioning load case is generally load carrying capacity with regard to permanent deformations, Figure 3. In a lightweight trailer chassis, where the thicknesses have been reduced and the working stress level is increased, the load carrying capacity and service life is limited by fatigue, elastic deflections and stability.

FIGURE 3   Trailers subjected to different loading situations during service.

a)   b)   c)   d)
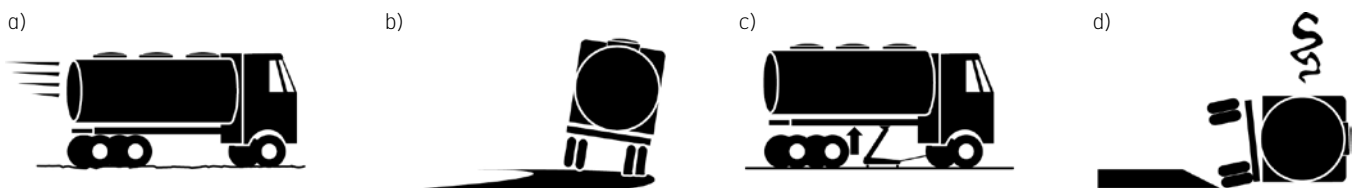
To achieve a successful upgrading it is important to take all loading situations into account, a) Fatigue at frequent low stress loading cycles, b) Elastic deformations when operating, c) Load carrying capacity; no permanent deformations at maximum loading, d) Stability when operating.

TYPICAL UPGRADING

Strenx 700 MC is commonly used in lightweight solutions for trailer chassis. Upgrading a trailer chassis from a 350-grade using Strenx 700 MC typically generates a weight reduction of about 30 % for the chassis structural parts, but depending on the chassis design, the weight reduction potential may be higher; even up to 50 %. As an example the potential weight reduction of an existing 13.75 meter long trailer main beam produced from a 350-steel grade by introducing Strenx 700 MC has been calculated. The load carrying capacity of the existing design has been determined and a matching alternative in Strenx 700 MC is suggested, Figure 4.

The total weight of the original main members manufactured from conventional steel is 1,085 kg and the total weight of the upgraded alternative in Strenx 700 MC is 704 kg. This gives a weight reduction of 381 kg or 35.2 %. These results should be considered as an example. Depending on the type of vehicle, specific requirements and design details, the upgrading potential may be less or greater compared to the example above. The calculations only consider static load carrying capacity, but serves as a good starting point in developing a lightweight chassis design.

For the main beams of a conventionally designed trailer chassis, there are some limitations in order to utilize a higher strength than Strenx 700 MC for the purpose of structural strength. In order to truly benefit from higher strength other concepts for the chassis need to be explored. However, for certain special trailers higher grades such as Strenx 960 may be an appropriate choice. For flanges or profiles subjected to wear or denting, such as the rear bumper and the bulkhead, a higher strength steel such as Strenx 1100 or a wear resistant steel such as Hardox 450 can be utilized. For other parts of the chassis, such as floor members, cold-rolled steels such as Docol 1000 DP and Docol 1200 M offer great opportunities for significant weight reductions. These parts can be produced by bending and, for larger series, roll-forming or stamping.

FIGURE 4   Lightweight solutions for matching load carrying capacity and bending stiffness.
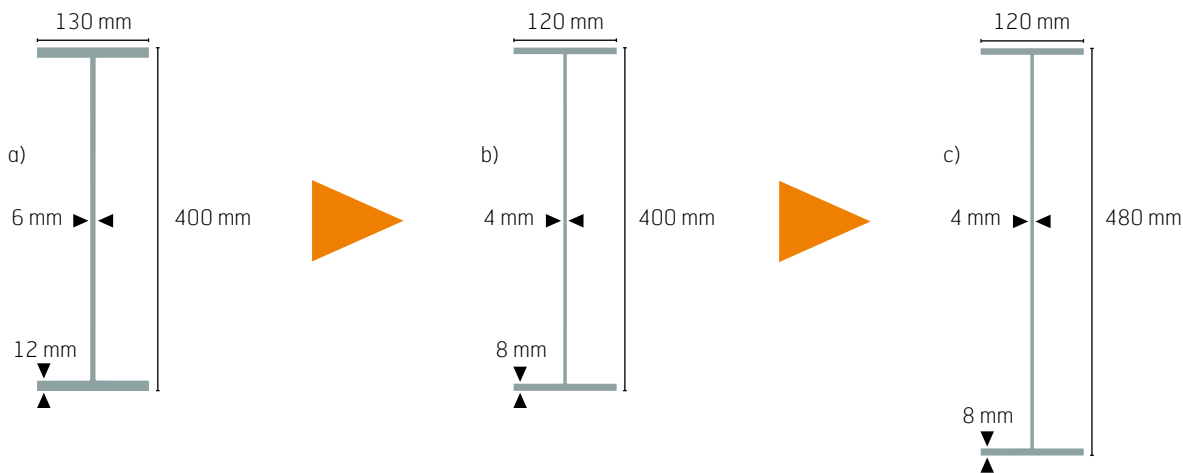
Overview of the cross-sectional properties and the weight reduction potential of a conventional main beam a) and upgraded, lightweight alternatives b) and c) in Strenx 700 MC.

	Original design a)	Lightweight design b)	Lightweight design c)
Steel Grade	S355	Strenx 700 MC	Strenx 700 MC
Weight, m [kg/m]	42	27	30
Bending Moment Capacity, M [kNm]	286	306	369
Moment of Inertia, I [m⁴]	140 E−06	93E−06	140E−06
Section Modulus, W [m³]	72E−05	46E−05	58E−05
Weight Reduction, WR [%]	–	36	30

BENDING STIFFNESS

Bending stiffness in the vertical direction is often pointed out as a critical aspect for lighter and stronger trailers in high strength steel. In certain markets the elastic deflections of the vehicles are regulated with regard to ground clearance, but in the majority of cases the limitations on deflections are a matter of functionality. That is, the deflections of the trailer chassis should not introduce problems in opening and closing doors, and of course there should be enough space between the truck and the trailer in the area of the fifth wheel when loaded. For certain special trailers, like low-bed trailers, the requirements on the elastic deflections may limit the choice of material.

Since all steel grades have the same Young's modulus, the bending stiffness is governed by geometry. That is, simply reducing the sheet thickness of the consisting profiles will give a reduced bending stiffness if the outer geometry is the same. For a trailer chassis the bending stiffness in the vertical direction is governed by the geometry of the longitudinal beams. If the stiffness reduction should pose a problem the bending stiffness may be improved by increasing the height of the cross-sections.

Increasing the height of the beam is the most efficient way to increase the bending stiffness. However, in areas where the height of the beam is restricted, the bending stiffness can be improved by increasing the flange width, Figure 5. This measure can also be taken in critical areas to reduce the working stress level and improve the stiffness in the lateral direction of the beams. Utilizing modern manufacturing techniques the flange width can be tailored over the length of the beam according to the load distribution. Although, since the thickness of the flange is reduced, the width can only be increased to a certain degree, otherwise the flange on the compressed side will be too slender and local buckling may occur, which will limit the material utilization of the flange. If the existing trailer beam is already very high, shear buckling of the slender web may limit the possibility to increase the height and reduce the thickness of the web. Instability and calculation methods are described further in the SSAB Sheet Steel Handbook[1].

STABILITY

The stability of the complete vehicle riding on the roads or, for tipper trailers, in an unloading situation depends on a number of different factors, where the torsional stiffness of the chassis is one component. For tipper trailers and other trailers where significant twisting loads are present this must be taken into account when upgrading the trailer chassis. The torsional stiffness of a chassis is governed by the design and the position of the cross-members and by the presence of cross-ties. Reducing the thickness of the web of the chassis main beams will have a very limited effect, while reducing the thickness of the cross-members will affect the chassis torsional stiffness significantly. In order to avoid stability stability problems, design changes can be introduced to reach a matching or even improved torsional stiffness, compared to the original design.

By introducing profiles with closed cross-sections for the cross-members the stiffness in torsion is significantly improved, Figure 6. But in order to get the optimum material utilization the position of the cross-members is equally important. Redistribution or introduction of one or two additional cross members influences the overall torsional stiffness. In general the cross members should be focused towards the rear part of the chassis. However, this shift has been exaggerated in practice many times, and by moving cross members forward or introducing an additional cross member in a strategic region of the front part, will improve the overall behaviour significantly. Since a small rotation in the front part results in big displacements of the rear, an increased torsional stiffness of the front could improve the overall performance.

Another effective measure is introducing cross-ties. To get the optimum material utilization of the cross-tie it is important to design it to only carry tensile loading in one bar and allow the other bar to buckle. Hence, the bars should be slender and not welded to each other at the centre. To illustrate the effect of these measures a comparison of the twisting angle corresponding to a torsional moment applied at the rear of a common tipper chassis is performed. The results from the calculations represent a unique case, but illustrate clearly the impact of these measures on the chassis stiffness in torsion. In all the calculated cases the total mass of the cross-members has been constant. That is, for the case where closed cross-sections have been used the thickness of the profiles has been reduced. The results show that reducing the thickness of the web gives a slightly reduced torsional stiffness compared to the original design. While introducing closed cross-members or a double cross-tie gives a significantly improved stiffness.

1. SSAB Sheet Steel Handbook, ISBN 978-91-978573-1-4.

FIGURE 5   Variable flange width can be introduced to improve the bending resistance and the bending stiffness in critical areas.
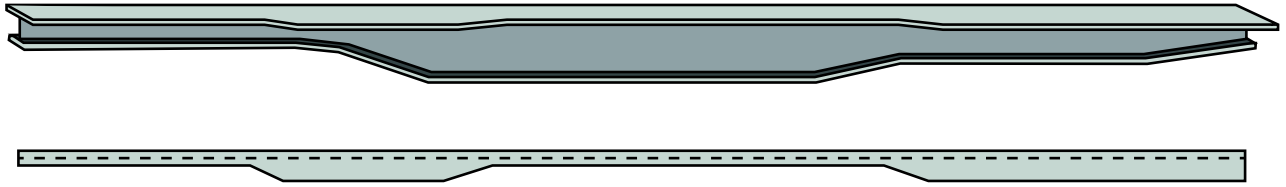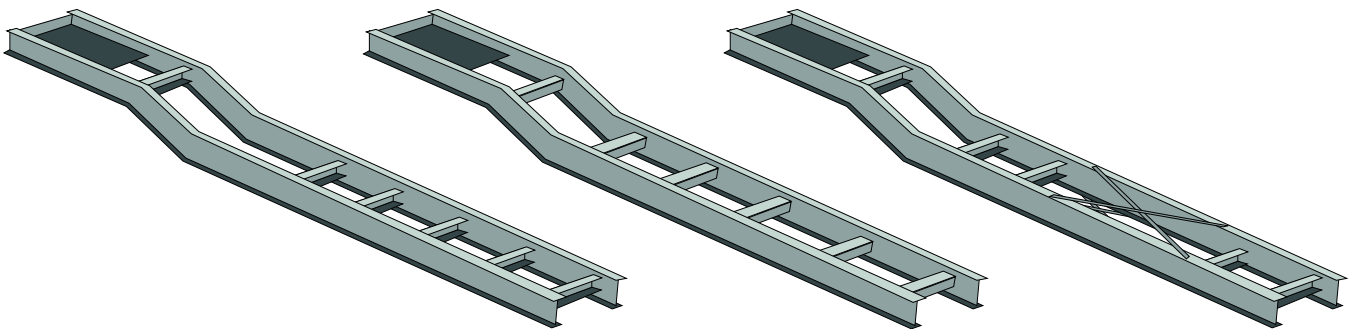

FIGURE 6   Comparison of the torsional resistance of a trailer chassis with open section cross-members to solutions with closed cross-member profiles and cross-bars.
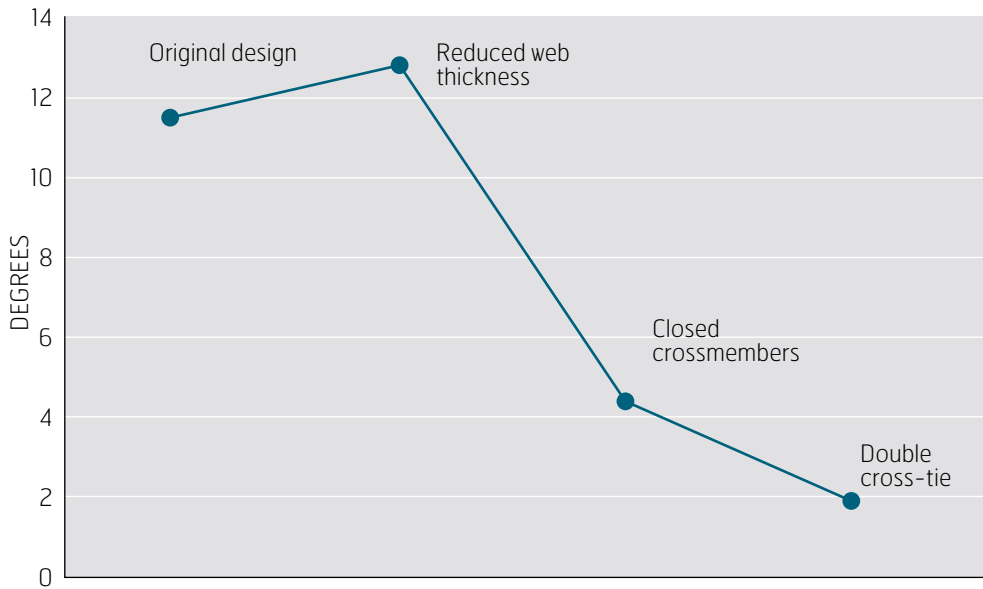
Original design   Closed crossmembers   Double cross-tie

FATIGUE

All trailers are subjected to fatigue loads during driving and loading. The load history that determines the life of a trailer chassis consist of the collected loads of varying number and magnitude. Depending on the type of trailer, road conditions and loading situation the appearance of the load history will vary accordingly. When upgrading a trailer chassis using AHSS the sheet thickness of the structural parts is usually reduced. Reducing the sheet thickness will result in an increased working stress level in the complete chassis. With a stronger material comes higher fatigue strength for the base material. For welded joints, however, this influence is limited due to the stress concentration and the initial imperfections introduced at the welds. Hence, fatigue life of welded joints is more a question of design and manufacturing than choice of material. If the same weld joint design and weld quality is deployed this will result in a reduced fatigue resistance for the chassis.

FATIGUE RESISTANCE

The fatigue resistance of a material is illustrated in S/N curves, which are created from fatigue testing of specimens using a load history of constant amplitude. That is, a specimen is subjected to the same load cycle repeatedly until failure. After testing of several specimens at different load levels a S/N curve can be plotted. At the upper left part of the curves in Figure 7 the fatigue resistance is governed by the static properties of the material. At the lower right part of Figure 7 the fatigue resistance is governed by discontinuities in the specimen. Discontinuities are for instance the surface texture from rolling of the sheet, cut edges, holes, notches and welds. They are mentioned in the order of decreased fatigue resistance.

WHY IS THE WELDED JOINT A CRITICAL AREA?

Welded joints have a significantly reduced fatigue resistance compared to the base material due to sharp geometry of the weld and the residual stresses introduced from the heat input during welding. It is common that the fatigue resistance of welds is discussed in relation to micro-structures, heat affected zones and hardness, but the major cause of the weakening of the weld is due to local stress concentration and defects. All post-treatment methods of welds are focused on reducing residual stresses and improving the weld geometry. To retrieve good fatigue resistance, it is important to have a smooth transition radius and angle at the weld toe, Figure 8.

START AND STOP POSITIONS

Start and stop-positions are the most critical part of a weld with respect to fatigue. Since the welding process is not in a steady state, the risk of generating defects and inclusions in these positions is higher. Therefore, due to their limited length, tack welds have lower fatigue resistance than continuous welds. Tack welding of longitudinal beams should be kept to a minimum and tack welds should be positioned in low stress areas. The weld between the upper flange and the web is less sensitive to tack welding, since this part is mainly subjected to compressive stresses. It is important to design welded joints in general to allow the start and stop of the weld to be placed in low stress areas. In some cases fish-tail design could be used to move the start and stop-positions away from the most highly stressed area as at the end of a reinforcement plate, Figure 9.

FIGURE 7   S/N Curves of specimens of rolled sheet, with punched hole and welded joint.
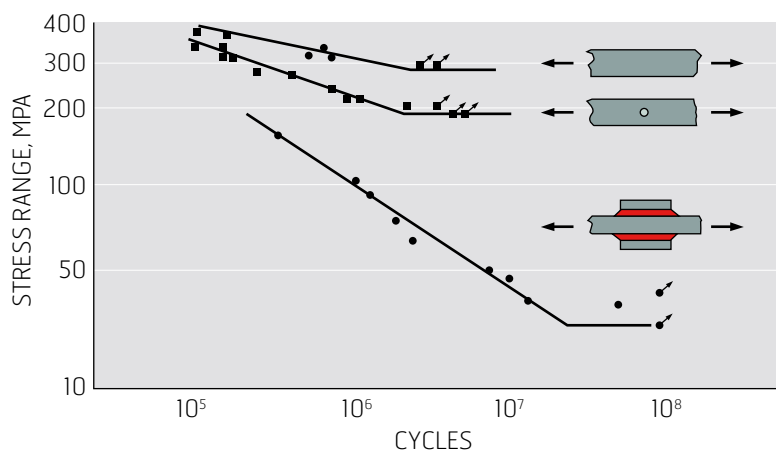
FIGURE 8   Sharp and smooth weld toe geometry.

K_t=5.6 K_t=1.6
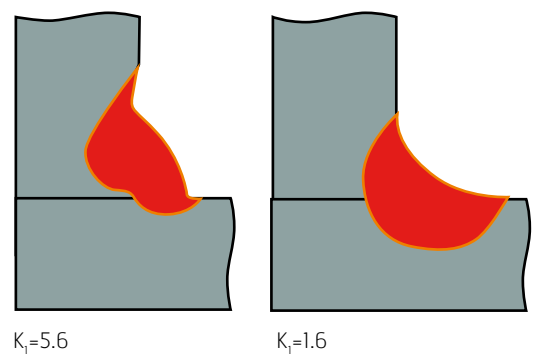
TRANSVERSE VERSUS LONGITUDINAL FATIGUE LOADING OF A WELD

Discontinuities in a weld are orientated in the welding direction and follow the root and weld toes. If the discontinuities are parallel to the principal stress direction they have small impact on the fatigue resistance of the weld. On the other hand, if the stresses are transverse to the weld direction the fatigue resistance of the weld will be very low. E.g. the fatigue life of an attachment bracket welded to the lower flange has less than 5 % of the fatigue life of the weld between the web and the flange.

LOAD HISTORY

The load history of trailers is irregular and random by nature, and the total number of load cycles during its life is in the region of 10^8–10^9 cycles. Even if the majority of the load cycles have a very small magnitude, combining them with larger loads still make them potentially critical for fatigue. One can perceive large loads as crack initiators and small loads as crack propagators. Due to these combined effects the fatigue limit found in constant amplitude loading vanishes in trailer applications. The only exception is when all loads in the complete history are lower than the fatigue limit. Therefore, in high stress areas, it is important that the welds have good fatigue resistance, such as welds loaded in the lengthwise direction. Welds with less fatigue resistance should be placed in low stress areas, e.g. near the neutral layer of the web of the main beams.

As an example, a comparison of an alternative design of an attachment bracket welded to a beam subjected to bending in the vertical direction can be made. When loaded in global bending the maximum stresses occur at the flanges of the beam and varies in compression and tension over the neutral layer. In the design at the top (a) in Figure 10 the attachment bracket is welded near the flanges with the start and stop positions of the weld located in the most highly stressed area of the beam cross-section. In the configuration at the bottom (b) of Figure 10 the attachment bracket has been redesigned to be plug welded closer to the neutral layer. This results in the stress level at the welded joint to be reduced by 50 %. Such a reduction in the stress level increases the fatigue life 8 times compared to the previous design.

COMMON PITFALLS

When upgrading from conventional steel to AHSS in order to develop a lightweight solution, there are some common pitfalls that can be avoided by some simple measures. The first and most important design advice is to keep it simple. Keep the number of parts to a minimum and utilize modern manufacturing techniques to integrate attachments and minimize the number of welded joints. For the chassis main beams it is recommended to use a single piece for the flanges and the web throughout the full length of the trailer. Such a solution reduces the number of welds, especially in the transverse direction, which is important from a fatigue point of view.

Reinforcement plates for both webs and flanges are commonly used with the intention to increase the load carrying capacity and the stiffness of the chassis. From a static point of view it may be possible to benefit from this measure, but from a fatigue point of view such designs do more harm than good.

In a main beam, manufactured from single pieces along the length without any reinforcement plates, the longitudinal weld of the I-beam will govern the fatigue life. When the trailer is loaded, the lower flange will be subjected to tensile stresses in the lengthwise direction in line with the weld. If a reinforcement plate is welded to the lower flange there will be a transverse loading of the welded joint which gives a reduction of the fatigue life by at least 8 times, Figure 11.

FIGURE 9   Fish-tail design can be introduced to move the start and stop-positions of a weld away from a high stress area.
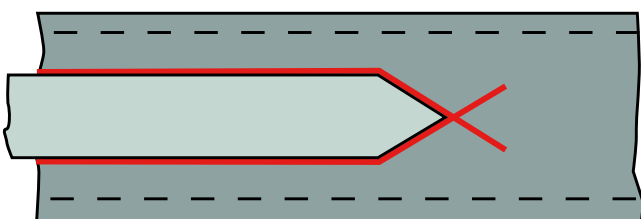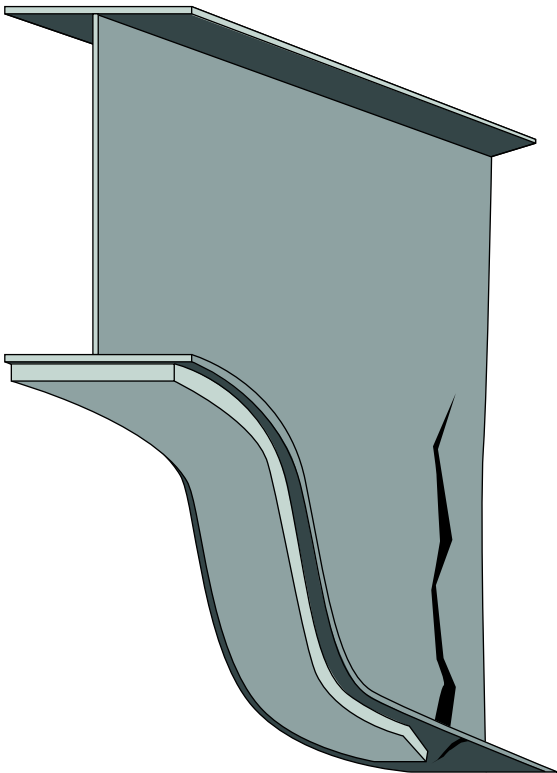

FIGURE 10   By redesigning the welded joints to be placed in low stress areas the fatigue life will be improved.
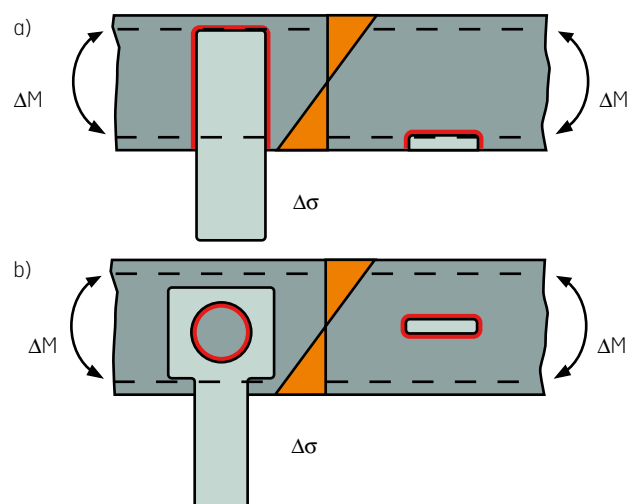
Introducing a reinforcement plate to the web or the flange also creates a stress concentration at the welded joint, since there will be a stiffness gradient in this area. Hence this weld joint will limit the fatigue life of the chassis and may cause cracking problems in an upgraded design where the working stress level is higher.
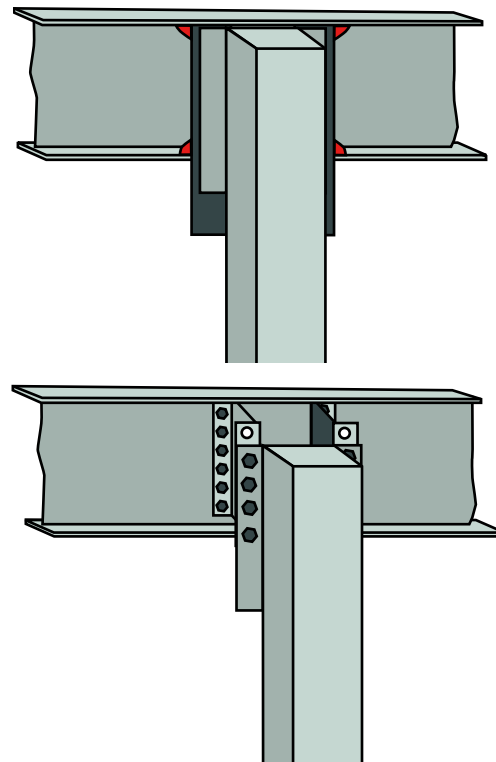
LANDING GEAR ATTACHMENT

One of the most critical areas on a trailer chassis is the goose neck region. Due to the transition in height, high stresses are present. This is generally not a problem for the static load carrying capacity of the trailer, but extra care has to be taken when designing secondary structures, such as the landing gear attachment, in this area.

If the landing gear attachment is designed to be welded to the flanges the weld joint will be in the most highly stressed area of the beam cross-section. Redesigning the attach-ment bracket to be attached to the web instead moves the weld joint into an area with lower stresses, Figure 12. This will improve the fatigue life of the weld joint substantially, see Example A.

FIGURE 11 Reinforcement plates welded to the lower flange will rapidly reduce the fatigue life.

FIGURE 12 To improve fatigue life of the landing gear the attachment should be placed close to the neutral layer of the main beam. A bolted connection will improve the fatigue life substantially.

In a conventional trailer chassis it is common to design the landing gear to be welded to a reinforcement plate that is attached to the lower flange in the neck region of the trailer, Figure 13. This weld between the landing gear and the rein-forcement plate is placed in a critical region, from a fatigue point of view. When developing a lightweight trailer chassis and reducing the thicknesses, the working stress level will be higher. This will give a reduced fatigue life for this weld if no redesign is performed. This example illustrates how a redesign of the attachment bracket affects the fatigue life.

The calculations are performed on a conventional main beam manufactured from mild steel (a) and an upgraded alterna-tive in AHSS (b) according to Figure 14. It is assumed that the fatigue life of this weld in the conventional trailer chassis is 16 years. It is also assumed that in the upgraded design the attachment bracket is welded directly onto the lower flange, without a reinforcement plate. The nominal stress due to bending of a beam is given by

$$\sigma = \frac{M_B}{W}$$

The second moment of inertia, I, and the section modulus, W, is determined by using Steiner's theorem or CAD software. As such, the stress at the weld in both alternatives can be determined according to

$$\sigma_b = \frac{M_B}{W_b} \quad , \quad \sigma_a = \frac{M_B}{W_a} \qquad \sigma_b = \frac{\sigma_a W_a}{W_b} = \frac{\sigma_a \cdot 685\,000}{348\,000} = \sigma_a \cdot 2$$

This shows that the stress level at the critical weld is 100 MPa in the conventional chassis. It will be 100 · 2 = 200 MPa in the upgraded trailer. The fatigue life of a weld has a relation in the power of 3 to the applied stress range; hence the fatigue life of the critical weld in the upgraded trailer will be reduced by

$$\left(\frac{\sigma_b}{\sigma_a}\right)^3 = 2^3 = 8$$

That is, the fatigue life of the critical weld in the upgraded design will be reduced from 16 years to $\frac{16}{8}$ = 2 years!
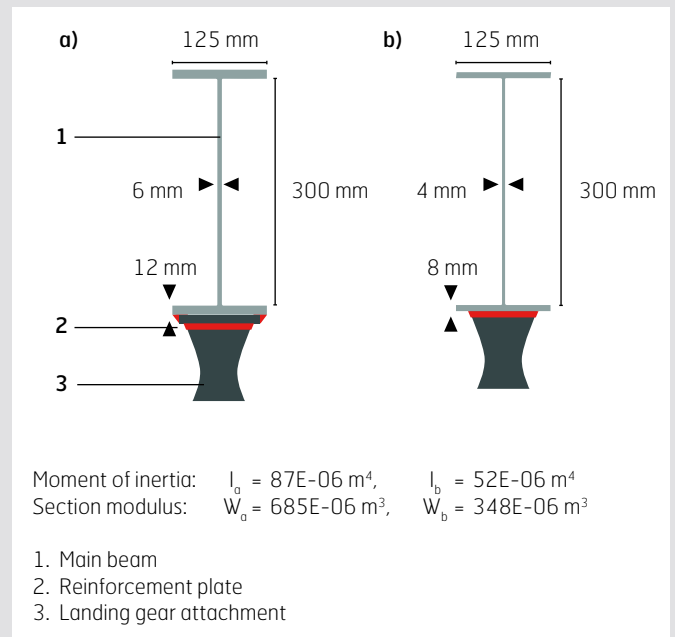
If the welded joint is redesigned according to Figure 10 in the previous section, and the critical weld joint is removed, the longitudinal weld between the flange and the web becomes the dimensioning factor from a fatigue point of view. The strength of a longitudinal weld is much higher than the trans-verse weld. If we compare the fatigue strength of these welds we find that the critical weld at the attachment has character-istic fatigue strength, FAT, of 63MPa but the longitudinal has FAT 125 MPa, Figure 15. This means that the longitudinal weld can tolerate twice the stress, than that of the transverse weld.

So even though the working stresses have been increased by a factor of 2 in the upgraded I-beam, by simple redesign the fatigue strength of the critical weld joint has been improved by a factor of 2. Hence, we have maintained the fatigue life to the original design.

FIGURE 13   Landing gear attachment welded to the reinforced lower flange of a conventional trailer main beam.
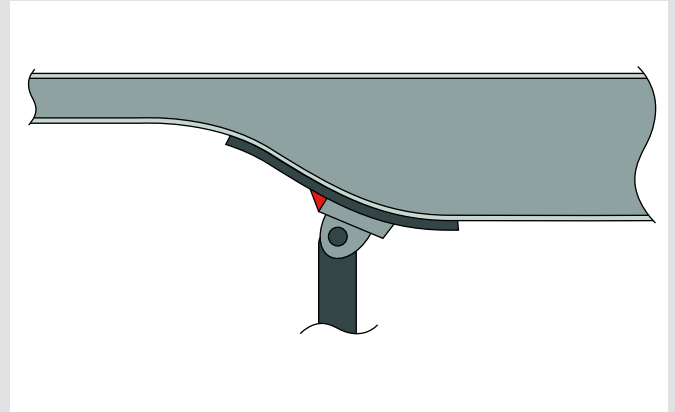
FIGURE 14   Geometry and cross-sectional properties of the conventional a) and upgraded main beams b) included in the calculations.

Moment of inertia: I_a = 87E-06 m⁴, I_b = 52E-06 m⁴
Section modulus: W_a = 685E-06 m³, W_b = 348E-06 m³

1. Main beam
2. Reinforcement plate
3. Landing gear attachment

FIGURE 15   Characteristic fatigue strength (FAT) of welded joints subjected to transverse a) and longitudinal b) loading

FAT 63   FAT 125 MPA
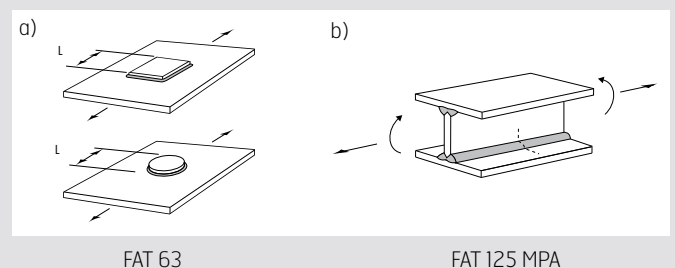
FIRST REAR AXLE ATTACHMENT

As for the goose neck area the hanger bracket region is a critical area on a trailer. Apart from vertical bending, lateral loads will be introduced in this area. Therefore it is important to avoid welding at the edge of the flanges, which are high stress areas.

In order to reduce the stiffness gradient between the hanger bracket and the lower flange it is beneficial to weld the bracket to an attachment plate. It is important that the plate has sufficient thickness and that the welds between the plate and the flange are positioned at least 20 mm from the edge of the flange. Variable flange width can be introduced to increase the bending moment capacity and the area available for attaching the hanger brackets. To improve the fatigue life further the hanger bracket attachment can be designed as a bolted joint, Figure 16.

Any web stiffeners taking care of the local vertical shear loads in this region should be positioned in line with the loading direction from the hanger brackets. Placing the stiffener at a distance from the hanger bracket will introduce an additional bending of the lower flange and reduce the fatigue life significantly.

CROSS-MEMBER ATTACHMENT

For trailers where the chassis is subjected to torsional loading, for example tipper trailers and timber carriers, it is strongly recommended to use profiles with a closed cross-section for the cross-members. In most cases such a solution allows the cross-members to be welded straight into the web without any additional reinforcements. For heavy-duty vehicles a web stiffener can be integrated in the cross-member attachment to increase the stiffness and reduce the stress level in this area, Figure 17.

Profiles with open cross-sections can be used in trailers where the cross-members are mainly subjected to bending, e.g. curtain-siders, container carriers and vans. Openings for every profile can be cut into the web and the profiles may be welded to the web plate of the longitudinal beam. However, it should be noted, though repeated, that profiles with open cross-sections are not recommended for chassis subjected to twisting loads.

Yet another solution is to use an attachment bracket to distribute the stresses over a larger area. The attachment bracket can be welded, riveted or bolted to the web of the longitudinal beam.

FIGURE 16 Placing the web stiffener at a distance from the hanger bracket introduces additional bending to the lower flange, which will rapidly reduce fatigue life.
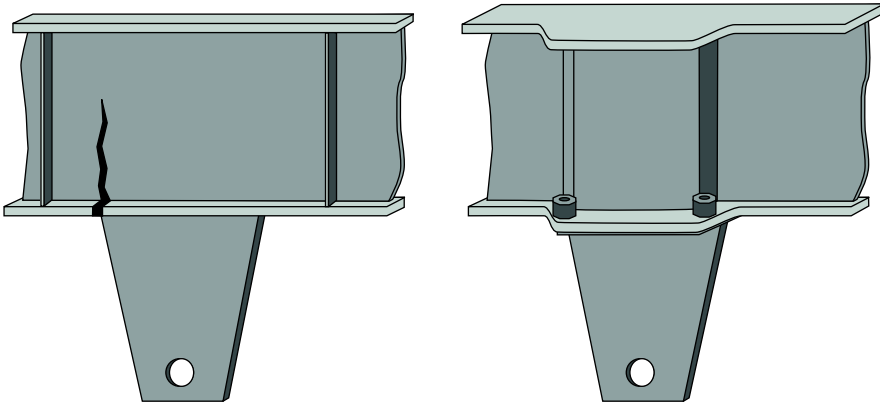
To improve the fatigue properties any web stiffener in this region should be positioned directly in line with the hanger bracket. Introducing a wider flange gives an increased resistance to side bending and enables the welds to be placed at a distance from the critical area at the lower flange. To improve the fatigue life even further a bolted joint could be introduced.

FIGURE 17 Different types of cross-member attachments.

a)

b)

c)
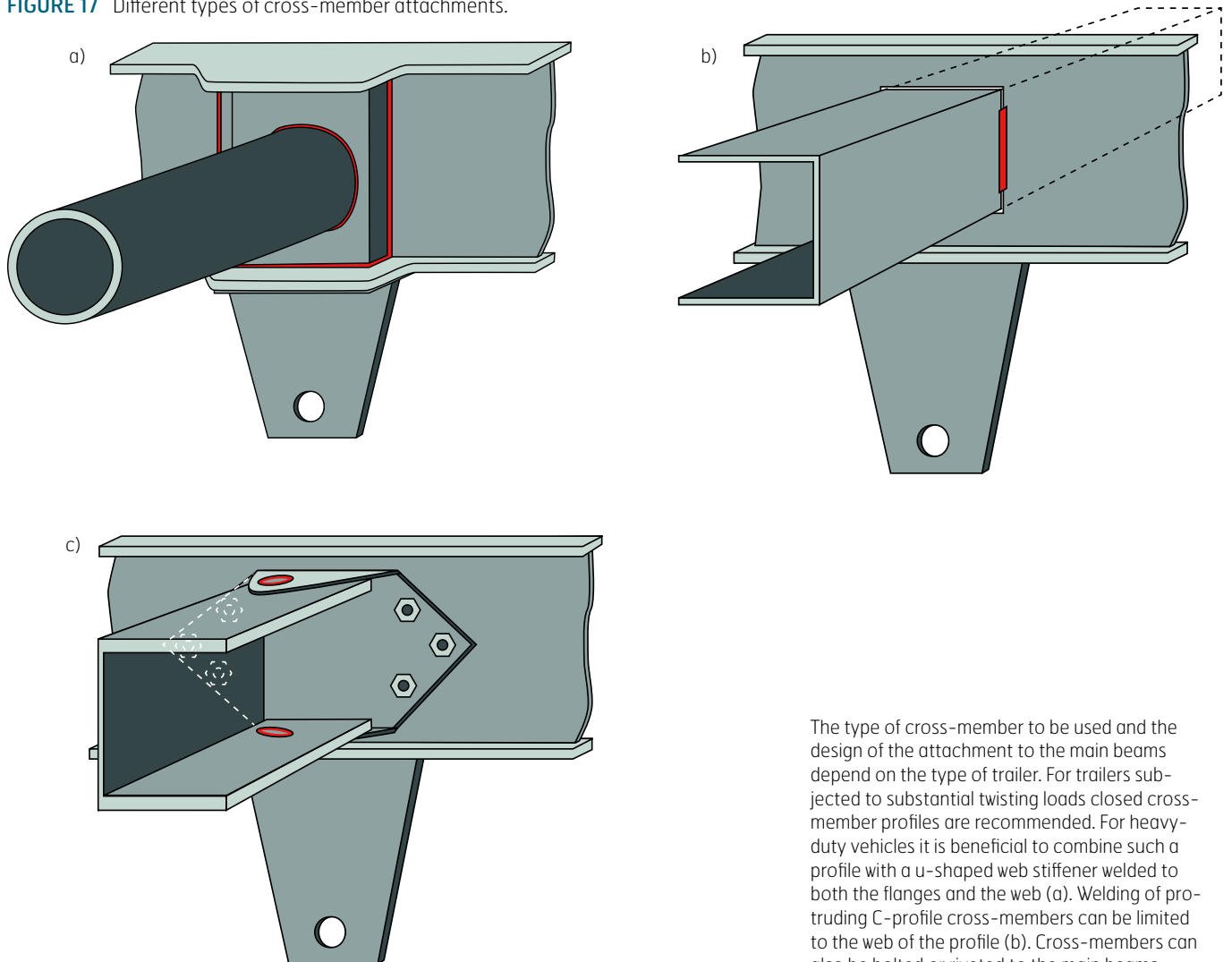
The type of cross-member to be used and the design of the attachment to the main beams depend on the type of trailer. For trailers subjected to substantial twisting loads closed cross-member profiles are recommended. For heavy-duty vehicles it is beneficial to combine such a profile with a u-shaped web stiffener welded to both the flanges and the web (a). Welding of protruding C-profile cross-members can be limited to the web of the profile (b). Cross-members can also be bolted or riveted to the main beams.

MANUFACTURING

Based on our experience the number one cause of fatigue failures in trailer chassis is due to poor weld quality. Therefore, it is important, not only to thoroughly evaluate the new upgraded design, but also to secure the production process. Poor weld or edge quality will rapidly decrease the service life of any trailer.

EDGE QUALITY

Edge quality is also important for fatigue resistance and different cutting methods result in different edge quality. Figure 18 shows the results of fatigue testing of Strenx 700 MC where the plate edge has been milled, laser-cut and sheared. Laser-cut edges are often better than mechanically cut edges. To achieve good fatigue strength of mechanically cut edges it is important to remove all visual crack-like defects. Modern thermal cutting processes like laser or high definition plasma generally produce edges in Strenx 700 MC with good

fatigue properties. The ranking of such methods from a fatigue point of view would be laser, plasma and manual gas-cutting. To avoid fatigue problems it is also important to place start and stop-positions in low stress areas. Blasting of a structure with cut edges normally has a positive effect on fatigue resistance.

HOT DIP GALVANIZING

Piecewise hot dip galvanizing is used in order to improve the corrosion resistance. Strenx High Strength Steels up to Strenx 700 MC are very well suited for hot dip galvanizing if ordered in a specific condition with a certain Si-content. The mechanical properties of the steels are generally not influenced by the galvanizing process; for instance there is no influence on the fatigue properties of welded joints. However, it could be no-

FIGURE 18   Results from fatigue testing of Strenx 700 MC with different edge conditions.
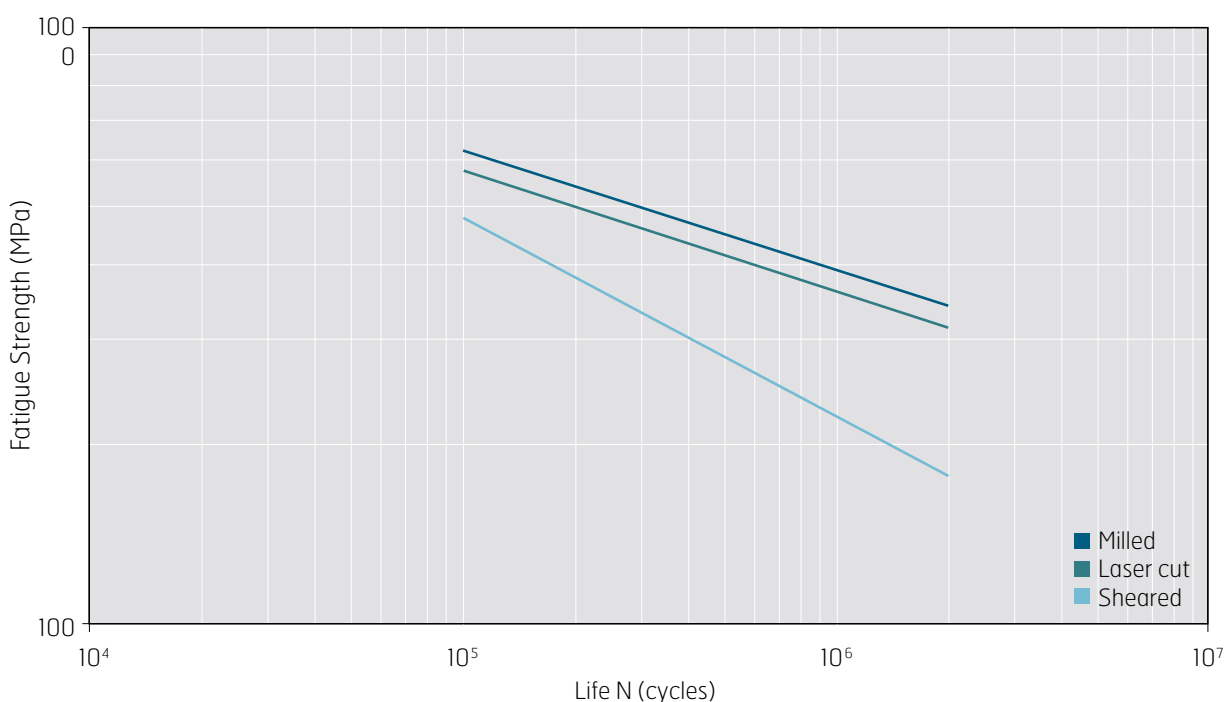
ticed that the fatigue strength of the base material is slightly reduced due to the zinc layer and the interface between the zinc layer and the steel surface. For Strenx 700 MC hot dip galvanizing typically reduces the fatigue strength of the base material by about 10 %.

FEASIBLE WELDING METHODS

All conventional welding methods can be used for AHSS. The most commonly used welding methods in the trailer industry today are:

- MAG-welding (with solid or cored wire)
- Submerged Arc Welding (sometimes used to produce the longitudinal beams)

FILLER METAL

The strength of the filler material should normally be matched to the strength of the base material, Table 3. However welds in trailer applications are very seldom subjected to stress levels that require matching filler metal. In most cases it is therefore possible to use undermatching filler metals. If Submerged Arc Welding is used for welding of AHSS, basic flux is recommended.

HEAT INPUT – STRENX

High strength steels are somewhat sensitive to high heat inputs. Excessive high heat input decreases the strength as well as the impact toughness of the welded joint. If the minimum yield strength of the base material must be fulfilled in the welded joint, the maximum recommended heat input should not exceed the values in Figure 19.

The graph in Figure 19 is valid for butt welds, welded with matching filler metal, and where the reinforcement has been removed before testing. The maximum interpass temperature is 100 °C. The heat input can be calculated according to Figure 20.

The arc efficiency values for SAW and MAG-welding are given in Table 4.

If the weld is located in a low stressed area and the impact toughness requirement is of lesser importance, higher heat inputs can be used.

HEAT INPUT – DOCOL

Docol AHSS are produced in thinner gauges, which makes it more difficult to decrease the heat input to such an extent that the heat affected zone can be limited to a level, where a base material failure can be achieved. As a rule of thumb: weld with as low a heat input as possible.

TABLE 3   Filler material for Strenx and Docol AHSS steels.

Steel Grade	MAG-welding (GMAW)	Submerged Arc Welding (SAW)
Strenx 700 MC	AWS: A5.28 ER100S-X AWS: A5.28 ER110S-X EN 12534: G Mn3Ni1CrMo EN 12543: G Mn4Ni2CrMo	AWS: A5.23 F10X AWS: A5.23 F11X EN ISO 26304-A S69X
Docol 1000 DP Docol 1200 M	AWS: A5.28 ER110S-X AWS: A5.28 ER120S-X EN 12534: G Mn3Ni1CrMo EN 12543: G Mn4Ni2CrMo	

FIGURE 19   Maximum recommended heat input (Q) for
            Strenx 700.
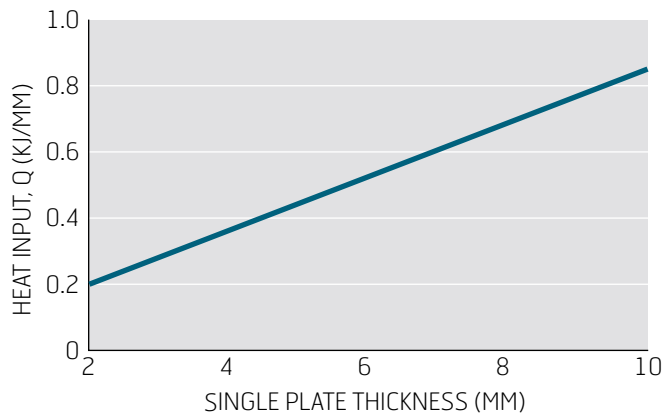
Maximum recommended heat input in order to fulfill the minimum yield
strength (Re) and impact toughness requirements at -40 °C.

FIGURE 20   Formula used for calculating the heat input.

$$E = \frac{U \cdot I \cdot 60}{v \cdot 1000} \text{ kj/mm} \quad Q = E \cdot k$$

U = Voltage, I = Current, v = Travel speed (mm/min),
k = Arc efficiency.

TABLE 4   Arc efficiency for different welding methods.

Welding method	Arc efficiency
MAG-welding	0.8
SAW	1.0

DISTORTION—STRENX

In practice for trailer applications, distortion due to welding is
more critical than the static strength of the welds. In order to
minimize the amount of distortion due to the welding operation:

- Weld with as low a heat input as possible
- Minimize the cross sectional area of the weld, Figure 21
- Prebend, clamp or angle the parts before welding in order
  to compensate for the shrinking
- Avoid irregular gaps in the root
- Use symmetrical welds, Figure 22
- Minimize reinforcements and optimize the throat
  thickness of the fillet welds
- Weld from rigid areas to loose ends
- Optimize the welding sequence

FIGURE 21   Cross-section of the weld and how it influences
   the angle deviation.
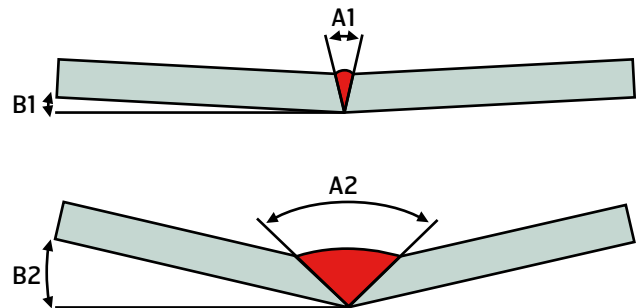
FIGURE 22   Use a symmetrical welding sequence.
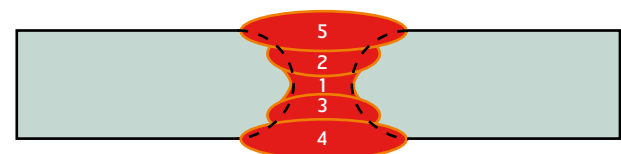
In order to avoid a curved/deformed longitudinal beam after welding of the web, displace the web in relation to the centre of the flange. This makes it possible to locate the longitudinal welds in the neutral layer of the flanges, Figure 23.

FIGURE 23   Displacing the web in relation to the flange makes it possible to weld in the neutral layer of the flange, which avoids deformations from welding.
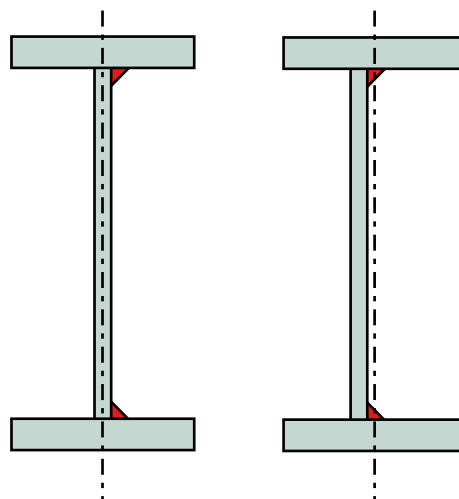
DISTORTION – DOCOL

In order to avoid heavy deformation on Docol steels the following is recommended:

- Weld with as a low heat input as possible
- Use a wire with a small diameter (0.8 mm).
- Downhill welding technique reduces the heat input and is recommended if permitted by the application and the production conditions.
- If the application allows a small gap between the sheets, intermittent welding can be used.
- If the application requires a sealed connection, silicon or adhesives could be used instead of welding to seal the connection and prevent corrosion to arise.
- Use lap welds instead of butt welds
- Welding of thin sheets requires a short distance between the tack welds.
- Power sources for MAG-welding have developed a lot lately which makes it possible to weld thin sheets with approximately 50 % lower heat input.
- If the joint is accessible from both sides resistance spot welding can be used instead of fusion welding.
- Avoid welding and use mechanical joining which guaranties very low or no deformation.

FIGURE 24   Pay attention to the stops, which are placed on the sacrificial plate. This plate is then removed by grinding.

FIGURE 25   Proper direction of the grinding scratches oriented longitudinal to the stress.

Weld

F

F

STRAIGHTENING

Hot straightening is a very common method to restore longitudinal beams for trailer chassis that have been distorted due to welding. It is not recommended to use hot straightening for Strenx and Docol AHSS. It is not recommended to use hot straightening for Strenx and Docol AHSS. This is because the steel may lose its guaranteed properties in the heated area.

The recommended maximum temperature these steels can be subjected to without loosing their guaranteed mechanical properties is:

Strenx 700 MC   650 °C
Docol 1000 DP   300 °C
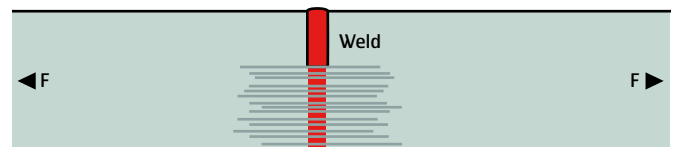Docol 1200 M   200 °C

WELD QUALITY

If the flanges of the longitudinal beam have to be welded (which is not recommended) in order to increase the length of the flange or beam use a temporary sacrificial plate for critical weld starts and stops. The temporary plate can easily be removed by grinding after welding. Figure 24.

Grind the edge with a smooth grinding wheel and make sure that the direction of the grinding scratches is longitudinal to the loading direction, Figure 25. Another alternative is to

design the weld joint at a 45 degree angle to the length of the flange in order to avoid a principal stress flow in the transverse direction of the weld.

Welding with rutile cored wires has the tendency to create very smooth transitions between the weld metal and the base material. This property could be used in order to increase the fatigue performance of the weld, especially in critical areas like the landing gear attachment and the hanger bracket attachments.

In order to secure the weld quality it is important that all welds are examined. Defects that are especially detrimental for the fatigue performance of the trailer are surface breaking weld defects such as:

- Undercuts
- Root defects
- Lack of fusion
- Cold laps
- All types of cracks

With a proper welding technique and knowledge about how these defects occur is it possible to avoid unnecessary repairing. Figure 26 a) through f) below describes the most common weld discontinuities, how they occur and actions to avoid them.

FIGURE 26   Welding defects, why they arise and actions to avoid them:
   a) Lack of penetration b) Undercut c) Lack of fusion d) Pipe e) Porosity f) Sagging.

a) LACK OF PENETRATION/ ROOT DEFECT

CAUSE
- Too small joint angle
- Too small gap
- Too large root face
- Wrong welding technique
- Too low heat input

REMEDIAL ACTIONS
- Increase the joint angle (45 – 60°)
- Increase the gap
- Adapt the root face in relation to the heat input (1 – 2 mm)
- Decrease the oscillation of the electrode
- Increase the heat input
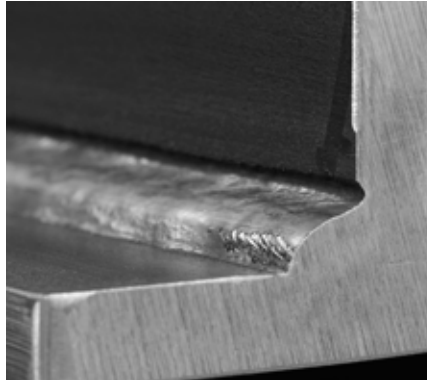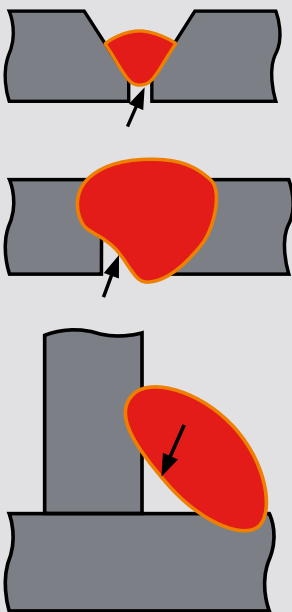
b) UNDERCUT

CAUSE
- Too high travel speed
- Incorrect oscillation technique
- Incorrect torch angle
- Too high voltage
- Too high heat input

REMEDIAL ACTIONS
- Decrease the travel speed
- Use small stops at the end of oscillation
- Neutral or a small forehand angle is beneficial
- Decrease the voltage
- Reduce the heat input
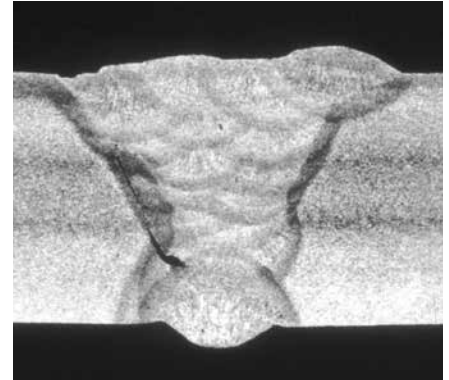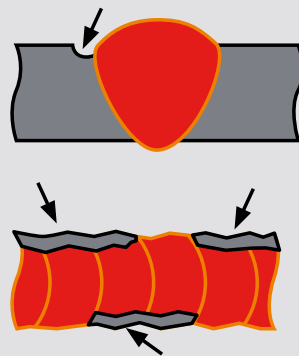
## c) LACK OF FUSION

CAUSE
- Travel speed too low (weld metal starts to flow in front of the arc)
- Travel speed too high
- Arc voltage too low
- Too long "stick out" distance
- Contact tip worn out
- Insufficient inter-run cleaning
- Welding in inclining position (downhill)

REMEDIAL ACTIONS
- Increase the travel speed
- Decrease the travel speed
- Increase the arc voltage
- Decrease the stick out distance
- Replace the contact tip
- Remove the surface slag prior to next run
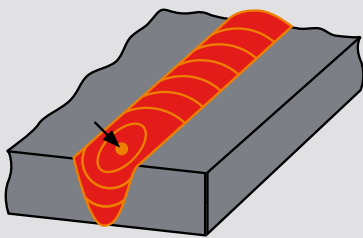- Adjust the travel speed in relation to the position
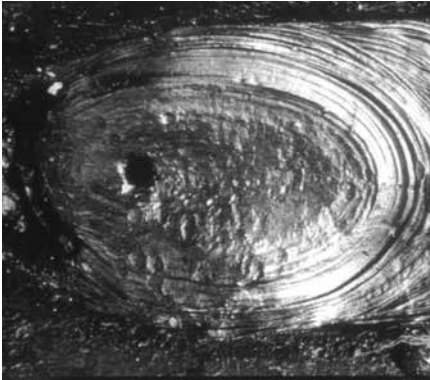
d) PIPE

CAUSE
- Wrong welding technique

REMEDIAL ACTIONS
- Use a proper welding technique. Reverse and re-ignite to fill up the crater. Larger beads/cross sections, might require a short cooling time
(2 – 3 s) before the crater is filled.

e) POROSITY

CAUSE
- Impurities in the joint (moisture, oil, corrosion, etc)
- Disturbing breeze
- Too high gas flow
- Too low gas flow
- Shielding gas contaminated (equipment)
- Injector effect
- Surface coating (zinc, primer)

REMEDIAL ACTIONS
- Keep the joint free from any impurities
- Control the equipment
- Control the gas flow
- Welding technique (torch angle)
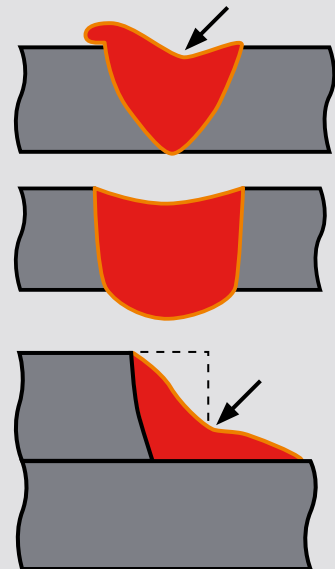- Remove surface coating
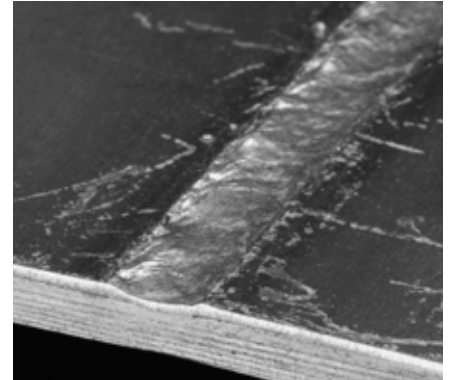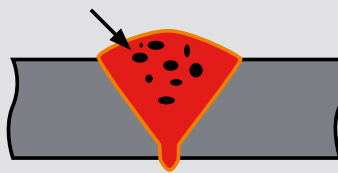
f) SAGGING (WELD CONCAVITY)

CAUSE
- Too high travel speed
- Number of beads too few
- Welding in downhill position

REMEDIAL ACTIONS
- Reduce the travel speed
- Use sufficient number of beads
- Switch to PA position (horizontal)

FOR THE FUTURE

Trailers of today have inherited the traditional chassis design from the first antique carts that was pulled by oxen or horses about 4.000 years ago. It is natural to think that new production techniques and more advanced materials would have promoted new design concepts for a product that has virtually remained unchanged since then, but it is only in the last 150 years steel was used in the vehicle structures and only about 30 years since advanced high strength steel (AHSS) was introduced. For modern vehicles invented during the 20th century, like the automobile and the airplane, a much faster development has occurred to improve design and reduce the weight promoted by mass production, demand for better performance or very high operational cost.

DEMAND FOR LIGHTER AND STRONGER VEHICLES

Today heavy road vehicles like trucks and trailers are facing very tough demands on transport efficiency and operational cost. There has been a natural increase in the use of AHSS for these applications; primarily in the yield strength range of 500 to 700 MPa. Taking this evolutionary step is quite easy and the 4.000 years old conceptual design still used for the trailer chassis can be upgraded to develop a stronger and lighter chassis by reducing the thickness and implementing local design improvements.

NEW STRONGER STEEL GRADES

However, we at SSAB have always been developing new stronger steel grades. Already today there are grades available with yield strength of 960 and 1100 MPa, which offers new opportunities and challenges in further product development. Although there are new, stronger grades available it does not necessarily mean that they can easily be adopted to the old design concept. Dimensioning of trailer chassis have traditionally been confirmed by years of experience, trial and error and nowadays some FEA-simulations and controlled testing. With the introduction of AHSS the material is permitted to work under higher stresses and larger elastic deflections if possible, but the wish to truly utilize the material employed in the sections finds its limit at any welded joint in the structures. Welded joints are one of the most restricting factors to keep cutting weight of the chassis due to their limited fatigue resistance. Therefore the introduction of post-treatment methods like TIG-dressing or UIT-treatment and alternative joining methods like bolting, riveting, clinching, adhesive bonding and other technologies can help to boost the use of higher steel grades. Development of even stronger and lighter chassis by introducing higher steel grades need a new design approach in which welding is kept to a minimum and where the load introduction permits a good material utilization to be achieved.

2000   2030

EXPLORING NEW DESIGN CONCEPTS

Introduction of thinner gauges and new manufacturing techniques enables completely new concepts to be explored. A self-carrying monocoque chassis, similar to the concepts used in the car industry, is an interesting solution. Such continuous structures of thin gauges also implies a need for a new approach on forming of the material, by introducing processes that today are uncommon in trailer production workshops, like roll-forming, and pressing. More advanced methods are also possible for these new materials, like 3D roll-forming and stamping. Continuous structures in thin gauges are often not only lighter, but also stiffer and offer the possibility of integrating components and functions in the same structure.

However, adopting new designs need a lot of effort to be put into understanding the structural behavior of the chassis under all load cases, and it is also necessary to investigate the stiffness requirements, fatigue resistance and crashworthiness of components like rear bumper or bulkhead.

Taking the next step in developing lighter and stronger trailers requires that all the experience of chassis design acquired over the years is combined with new knowledge in a number of areas, where material knowledge and material selection play an important role. We at SSAB are happy to share our knowledge in this area and are always eager to assist our customers.

FIGURE 27   Fuel consumption and greenhouse gas emissions per one-ton mile.

Fuel consumption per one-ton mile

Cargo ship: 1x

Freight train: 1.6x

Truck: 10x

Ariplane: 47x
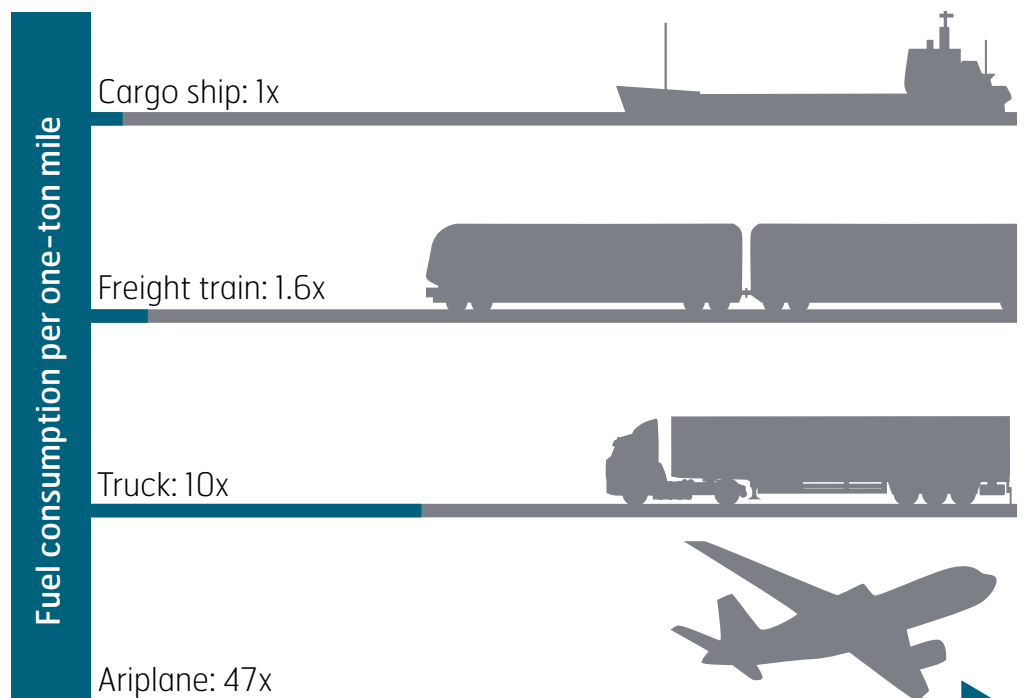
SSAB

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