Design of high strength steel for long member of trucks and commercial vehicles

BY

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SYNOPSIS:

The demands by the automotive industries to meet the environmental concerns such as global warming, CO2 emission etc. require materials for weight saving for fuel efficiency. Among the metallic materials that would meet these conflicting demands, steel has been proved to be the only choice available yet. The reduction in sheet thickness by use of high strength steel is being increasingly adopted as an effective means for weight reduction and increase in payload.

In this paper Essar Steel's experience in development of high strength S650MC/ 80Ksi grades steels for long member application in heavy duty commercial trucks is presented. These grades have been substituted in place of conventional 420 and 460 MPa strength steels. These high strength grades are designed to meet the complex loading behavior of long members and also provide significant weight saving potential. Details of metallurgical product strengthening, design principles, performance of material in actual line production are presented.

Keywords: High strength steel, long member, bainite steel, HSLA steel

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Introduction:

Transportation industry plays a major role in the economy of modern industrialized and developing countries. The total and relative volume of goods carried on trucks is dramatically increasing.

The major focus in the truck manufacturing industries is design of vehicles with more payload. By using higher strength steels than the conventional ones, significant weight reductions are possible with corresponding increase in payload capacity. The chassis of trucks which is the backbone of vehicles that integrates the main truck component systems such as the axles, suspension, power train, cab and trailer etc., is one of the possible candidates for significant weight reduction.[1-2] Substitution of higher strength steels for the chassis member offer substantial weight saving possibilities to the tune of 20% through proper design of the chassis members. However the metallurgical design
and properties needed for this application have to be carefully tailored to the end application since this component is the most critical component in the heavy vehicles. In this paper, the substitution of a high strength alloy (550 and 650 MPA YS) in place of conventional 420 MPa strength steel for a chassis frame of a 15 ton truck is presented. The metallurgical design factors of development of the high strength alloy, the loading and service life of a long member in the vehicle is briefly presented. Finally a case study of practical application in a vehicle is given.

**Engineering Aspects of a Long Member in a Truck**

Chassis frame consist of two channel shaped side member / long members, which are held apart by series of cross members (Figure.1). Cross members are positioned at points of high stress and are cold riveted to side member. The depth of the channel must be sufficient to minimize the deflection. Since the load at each point of the frame varies, a weight reduction can be achieved by either reducing the depth of the channel, or having a series of holes positioned along the neutral axis in the regions where the load is not so high.

During movement of a vehicle over normal road surfaces, the chassis frame is subjected to both bending and torsional distortion. The open-channel sections exhibit excellent resistance to bending, but have very little resistance to twist. Therefore, both side and cross-members of the chassis must be designed to resist torsional distortion along their length. Generally for heavy commercial vehicle channel section is preferred over hollow tube due to high torsional stiffness. The chassis frame, however, is not designed for complete rigidity, but for the combination of both strength and flexibility to some degree.

The chassis frame supports the various components and the body, and keeps them in correct positions. The frame must be light, but sufficiently strong to withstand the weight and rated load of the vehicle without having appreciable distortion. It must also be rigid enough to safeguard the components against the action of different forces. The chassis design includes the selection of suitable shapes and cross-section of chassis-members. Moreover, the design should consider the reinforcement of the chassis side- and cross-member joints, and the various methods of fastening them together. [3]
The design of an automobile chassis requires prior understanding of the kind of conditions the chassis is likely to face on the road. The chassis generally experiences four major loading situations, that include, [4]

i. vertical bending
ii. longitudinal torsion
iii. lateral bending,
iv. horizontal lozenging.

In addition there is torsion loading and fatigue loading.

Hence the material selected for this member must withstand the high bending loads, torsional loads and fatigue. In addition corrosion resistance is also important. Apart from chemical and mechanical properties, the critical requirements of this product are: —
i. Thickness Tolerance – No negative thickness and narrow band thickness
ii. Camber – Max camber spec is 1mm/meter – can effect flange height of C channel
iii. Length & Width Tolerance – No negative in length and width.
iv. Grain Size 7 or Finer
v. Micro alloying element should not exceed 0.20
vi. Material should be free from sliver, lamination, scabs and deep rolling marks.

**Manufacturing of Long Members**

Long members are made either by roll forming or press forming operations. Sometimes hydro formed components are used where stiffness supersedes other criteria


Sheet metal forming processes are those in which force is applied to a piece of sheet metal to modify its geometry rather than remove any material. The applied force stresses the metal beyond its yield strength, causing the material to plastically deform, but not to fail. By doing so, the sheet can be bent or stretched into a variety of complex shapes. This conventional process is used for grade to the strength level of 460 MPa.


Roll Forming is a continuous bending operation in which a long strip is passed through consecutive sets of rolls or strands, each forming only an incremental part of the bend until the desired cross section profile is obtained. Roll Forming is carried out in multi stages and is considered to be the most ideal and economical manufacturing process for bulk quantity production.

![Figure.2 Roll forming operation](image-url)
Following are the advantages of Roll Forming line over conventional press forming –

i. Dimensional consistency
ii. Low spring back
iii. Adjustable roller facility in the machine enables to use the same tooling for different sections. Same set of roller can be used for different thickness and wedge width.
iv. Input raw material is slit coils and the single line follows leads to lower man power cost.

[3]Hydro forming operation –

Hydro forming / Hydro form is a manufacturing process where fluid pressure is applied to a metallic blank / Tubes to form a desired component shape. This process requires hydro forming tools consisting of a punch made in the shape of the desired part, a ring contoured to fit around the punch, and a pressurized forming chamber sealed by a flexible rubber diaphragm. Tube hydro forming changes the cross-sectional shape of a tube from the normal round to other shapes that change along the part's length.

Tooling for a hydro formed part is typically less expensive than for a deep drawn part, since only a punch and ring are required. Deep Drawing requires a punch, die, and blank holder.

If the part is conducive to hydro forming and relatively small quantities are desired, hydro forming provides a cost effective solution to forming the part.

Currently, it is being done for passenger car and SUV only.

Design of Alloy

Based on the details of process of manufacturing the component and critical properties needed, the alloy has been designed to meet the required properties viz.,

- Strength
- Fatigue
- Corrosion
- Hardness
- Bending strength
- Minimum spring back
- Uniformity of properties

High strength micro alloyed ferrite bainite steels, dual phase steels, ultra high strength steels are some of the grades which are recently developed world wide to meet all of the above properties for these advanced special applications.

Yield strength in excess of approx 420MPa in reasonable thicknesses and with good toughness could only be attained in micro alloyed (MA) steels with low transformation temperatures. Micro alloyed high strength steels processed at controlled temperatures
has mixture of polygonal, and bainitic and ferrite. [5] This evolution of microstructure during controlled rolling is schematically explained in Fig 3.

Figure 3: Evolution of plate for long member: microstructure and mechanical properties [6]

**Strengthening Mechanism:** High-strength steels generally fall into three basic categories, classified by the strengthening mechanism employed.

i. solid-solution-strengthened steels  
ii. grain-refined steels or High strength low alloy steels (HSLA)  
iii. Transformation-hardened steels.

Solid solution strengthening relies mainly on addition of Mn, Si and C and P for strength. However, alloys solely based on solid solution strengthening mechanism lack formality and have low n value. Grain refinement technique to increase strength as well as toughness is the most effective metallurgical way to achieve combination strength, formability, toughness and elongation. Ti, Nb, V etc., are extensively used as an alloying element to achieve the combination of these critical properties. Another advantage is that these alloys can be designed with low carbon content for easy weldability. Titanium in low carbon steels forms into a number of compounds that provide grain refinement, precipitation strengthening and sulphide shape control. However, because titanium is also a strong deoxidizer, titanium can be used only in fully killed (aluminum deoxidized) steels so that titanium is available for forming into compounds other than titanium oxide.

Addition of titanium to low carbon niobium steel results in overall improvement of properties. Ti increases the efficiency of Nb, because it combines with the nitrogen, forming titanium nitrides. This allows for increased solubility of Nb in the austenite resulting in subsequent increased precipitation of NB(C, N) particles in the ferrite. The
addition of 0.04% Ti to steel strip containing various amounts of Nb consistently produced a YS increase of about 105MPa.[7]

In the present study, the steel chemistry is chosen such that the steel is formable with a critical YS/TS ratio needed for forming of cross members. Accordingly the strength was realized through alloying additions as well as micro structural engineering. The alloy design is based on grain refinement and precipitation hardening. By proper cooling rate selection, the secondary phase such as bainite was controlled with specific volume fraction. Further strengthening was achieved through micro alloy precipitates and solution hardening elements such as manganese and carbon and other alloying elements. Solid solution strengtheners such as manganese, and silicon and additives of grain refiners – niobium and titanium provide the required strength levels. Typical mechanical property and chemistry of these grades are given in table 1 and 2 respectively.

Table 1. Typical mechanical properties of high strength grades for chassis applications developed at ESSAR

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>EN Standard</th>
<th>460MC</th>
<th>550MC</th>
<th>650MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>YS (Mpa)</td>
<td>460 Min</td>
<td>550 Min</td>
<td>550 Min</td>
<td></td>
</tr>
<tr>
<td>UTS (Mpa)</td>
<td>520 - 670</td>
<td>600 - 760</td>
<td>700 - 880</td>
<td></td>
</tr>
<tr>
<td>El% (5.65 SqrtSo)</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Bend</td>
<td>1t</td>
<td>1.5t</td>
<td>2t</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Typical chemical compositions of micro alloyed high strength grades.

<table>
<thead>
<tr>
<th>Chemical Properties</th>
<th>Typical Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element</td>
<td>460MC</td>
</tr>
<tr>
<td>%C (max)</td>
<td>0.060-0.090</td>
</tr>
<tr>
<td>Mn(max)</td>
<td>0.650-0.900</td>
</tr>
<tr>
<td>Si(max)</td>
<td>0.030 Max</td>
</tr>
<tr>
<td>S(max)</td>
<td>0.004 Max</td>
</tr>
<tr>
<td>P(max)</td>
<td>0.010 Max</td>
</tr>
<tr>
<td>Al(min)</td>
<td>0.020-0.050</td>
</tr>
<tr>
<td>Nb(max)</td>
<td>0.038-0.063</td>
</tr>
<tr>
<td>V(max)</td>
<td>---</td>
</tr>
<tr>
<td>Ti(max)</td>
<td>0.012-0.028</td>
</tr>
</tbody>
</table>
Steel Making and rolling

The details of alloy design and steel making at ESSAR for this application are described below.

The material for cross member and chassis application must have excellent fatigue strength and good elongation. Clean steel without inclusions or exogenous second phase particles is a must to ensure long fatigue life during service. Special features of clean steel production through secondary refining techniques included electric arc furnace, ladle refining, vacuum arc degassing, and inclusion shape control by calcium. In addition, to control the segregations and inclusions, the steel was cast through vertical moulds and soft reduction to minimize metallurgical length.

The temperature controlled thermo mechanical rolling is done at the hot strip mill through carefully controlled heating, rolling and cooling sequences. These conditions give the steel there characteristic combination of high strength, good formability, weldability and Impact strength. The low contents of carbon, phosphorous and sulphur and homogeneous ferrite structure without any undesirable widmanstättn ferrite structure enabled all conventional welding methods to be readily used.

- Optimum alloy additions.
- Desulphurization for low levels of sulphur.
- Calcium treatment & inclusion shape control.
- Temperature control

- Degassing for low levels of gaseous contents.
- Argon stirring for homogeneity.
- Alloy trim additions for final chemistry.

- Vertical mould caster for low entrapments
- Automatic mould control, shrouding for good quality.
- Soft reduction for improved internal soundness.

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Micro Structure Details for S460, S550 and S650MC

Bainite is formed by adopting a cooling rate fast enough to suppress the Pearlite transformation and yet not rapid enough to produce bainite. The practical advantage of bainite steels is that relatively high strength levels together with adequate ductility and toughness. Microstructure of S460 grade consists of ferrite & Pearlite and S550/S60 consists of ferrite, pearlite & bainite.

Typical microstructures of 460, 550 and 650 grades are given in figure 4 and 5 below:

Figure.4 Ferrite + Bainite at 500X

Figure.5 Ferrite +Pearlite at 100X

Inspection Procedure –

i. Long Member and assembly are checked on Coordinate measuring machine (CMM) for the following dimensions:
   - Flange Height
   - Wedge Width
   - Hole Position & Center Distance (Mounting and Location hole)
   - Hole

ii. On line inspection is done for Width and Flange height of the long member

iii. Fixtures are used for checking the center distance of the holes.

iv. Radius is checked through Radius Gauge

Figure 6: Inspection of long member made from S 650 steel for truck
Case Study: Substitution of high strength steel (550MC/650MC) for long member application against the conventional used grades (460MC class)

The steel was used for making chassis for 25 T truck as well as small 10T trucks. Earlier two grades of steel were used in the 25 T truck models of Mahindra and Mahindra: 420 MPa steel for cross members and 460 MPa for long members. By using the high strength 550 MPa grades, it was possible to design the chassis as a single frame without any cross members thus avoiding reinforcements and also weight savings through design. This is for the first time that 25 T truck chassis member was made with a single frame with high strength steel. In another model of the truck of Asia Motor Works, the long member was made of 7 mm thick 460 Mpa strength steel with additional reinforcement of 5 mm. With the use of 650 MPa grade, the additional 5 mm reinforcement along the entire length was eliminated except for a small localized reinforcement at rear axle. Currently the vehicle is under field tests and the performance is satisfactory. In the case of 10T trucks, it was possible to reduce the thickness from 7mm to 4mm by using 650 MPa grade in place of 460 MPa steel. The recently launched heavy duty truck of Tata Motors, international trucks of Mahindra and Mahindra’s Navy stars and Asia Motor Works Global trucks in India have used these high strength products realizing weight savings to the tune of 17% and also increased payload.

In the initial supply of 550 MC grades, post press forming, bow was observed in the range 20 to 40mm which led to difficulty at the time of assembly of frame. One of the potential causes for bow variation identified was mechanical properties variation within the coil and within the lot of different coil.

Based on feedback, back tracking for finishing temperature (FT) and coiling temperature (CT) was done. HSM process parameter was studied and CT of the coil was controlled in the narrow range.

1 coil each of 9.5mm and 10mm thickness of SRDPS60 – 80KSI steel has been taken up for homogeneity test to ascertain uniformity of mechanical properties along the length of the coil. Both the coil i.e. 9.5mm and 10mm thickness was decoiled and sheared to plates with sampling at various lengths as provided in the table. The samples were evaluated for mechanical properties viz. – YS, TS & %El. The spread of variation of YS and TS is shown in figure 7.

![Figure 7 Statistical data of YS and TS after modification](image-url)
Further rolling was done with the fine tuned process parameters and regulars commercial supplies then commenced.

Conclusions

Substitution of ferrite bainite high strength alloy with for long member of a heavy truck fulfils the complex loading requirements during service.

The high strength alloy has been designed meeting the fatigue, strength, and other critical properties needed for this component. Solution hardening, microstructure control and precipitation hardening are main design philosophy employed in making the steels.

Saving of weight by about 17% was achieved by substitution of this high strength steel with 550 /650 MPa in place earlier practice of using 420/460 MPa strength.

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References: