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Tank Car Steels to Improve Performance

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Abstract

The Association of American Railroads (AAR) continues to strive for improved tank car performance by studying selected materials to match or exceed current industry standards and practices. To that end the industry task force on tank car steels (T95.7.1-95) as formed by the AAR Tank Car Committee meets regularly to consider existing and new steels to meet this challenge. Reported here are the most recent activities of this committee as well as a summary of considered steels to meet this industry goal. A planned testing program is also documented.

Introduction and Background

Interest in tank car steels is generated from a number of different perspectives and stakeholders:

- car owners and equipment operators desirous of improved steel performance when tank cars are involved in accidents
- regulators wanting safer tank cars for the public and railroad workers
- tank car builders wanting formability, weldability, availability, and low cost
- researchers wanting to progress improvements for all the aforementioned reasons and because they have quantified the benefits and desire to see them borne out in service
- steel companies want more performance from their products and where possible to reduce the plethora of material grades processed in their mills

While the industry task force (T95.7.1-95) initially had a singular task of looking at potential new steels for tank cars, it has been assigned other industry interests, including:

- upper limits of tensile strength for AAR TC128-Grade B material
- increased amounts of Silicon (Si) in TC128-Grade B

Therefore, over the last couple of years the committee has considered additional candidate steels to meet the desires of the stakeholders as well as working on contemporary challenges and opportunities with existing tank car steels.

Identifying Candidate Steels

A 2004 report on candidate steels[1] reported on shortcomings of the evaluated steel for improved performance, ASTM A841-Grade C Class 2. These shortcomings were identified during the metallurgical evaluations after heads were formed from the material at elevated temperatures. Sample coupons were also evaluated at 1100, 1200, 1300, and 1600 degrees Fahrenheit. The formed specimens that performed poorly when evaluated by Charpy "V" notch impact testing showed ferrite-pearlite banding due to elemental segregation. Martensite streaks were observed in the segregation bands.

The likely cause of this reported performance deficiency is centerline segregation during the (casting) manufacturing process. It is further thought that centerline segregation is exacerbated by thicker slabs and higher manganese levels.

There was no base case in this study against which ASTM A841 could be compared. Therefore it is not known if current industry standard material TC128-Grade B would exhibit some of these same shortcomings. The task force has resolved to include such baseline testing in future studies.

For a variety of considerations, three candidate steels were selected during the current evaluation process:

1. High-strength, Low-carbon, Ferritic, Copper-Precipitation Strengthening Steels (as developed by Northwestern University)
2. API 5L X-70 line pipe steel (as produced by IPSCO)
3. HPS 70W steel conforming to ASTM A709 (as produced by Arcelor-Mittal Steel)

The first steel does indeed show promise for the desired properties for tank car steels [2] as reported at the 2004 MS&T Conference. Several small laboratory heats have been melted and two 80,000 kg heats were produced at Oregon Steel Mills. These slabs were successfully hot rolled at US Steel Corporation Gary Works and one of the heats was used for rehabitation work of a bridge in Illinois.

However, this product has not been commercialized to the extent of being able to obtain sample plates for head forming. Therefore, for the current plan, this material is not being considered.

The second steel, X-70 line pipe steel, is commercially available and IPSCO has produced millions of tons of line pipe steel plates of this or similar material.[3] While API 5L X-70 meets ASTM A841- Grade F – Class 6, IPSCO forms thinner slabs out of their casters, which is thought to reduce or eliminate centerline segregation. (Individual producers can also select levels of alloying elements which benefit their production operation and final product quality.) It has been observed that Manganese (Mn) levels of 1.5% will certainly cause centerline segregation. See Table 1 below for comparisons between material grades for Mn content.

Manganese Content	
Material	Mn
TC128-Grade B	1.65 max
ASTM A841-Grade C	1.60 max
ASTM A841-Grade F	1.70 max
ASTM A709-Grade HPS 70W	1.35 max
ASTM A516-Grade 70	1.20 max

Table 1

The task force recognizes that IPSCO is limited in their width capacity to 122”. This makes them very viable for tank rings but not for head forming.

The third steel, HPS 70W has been produced in large quantities for the fabrication and construction of highway bridges.[4] In addition to low Mn, HPS 70W is calcium treated for sulfide shape control. Arcelor-Mittal Steel alone has produced 30,000 tons of this material.

Test Plan

The task force has decided that the critical operation for any of these materials is the head forming. The martensite streaks observed in the previous testing of A841 was tempered to produce ferrite and carbide but toughness did not improve. Therefore, the most critical or highest hurdle is to produce a tank car steel that can be warm formed without the attendant problems seen in earlier testing.

Since Arcelor-Mittal has the steel with lower Mn and can produce widths large enough for head forming, it was decided to proceed with head forming of the HPS material. A similar series of metallurgical tests as well as physical tests will be conducted, as was done with the ASTM A841 material earlier.

However, since the Charpy specimens are being taken from an area of the head not normally studied, it was decided to evaluate the current industry standard tank car material TC128-Grade B. This comparison is an important reality check on the acceptance criteria for any new tank car material.

It is planned for Arcelor-Mittal Steel to produce plates at 5/8” thick at a dimension large enough for both head forming as well as material for separate physical specimens to be obtained out of the unformed material. This is a tentative list of plates needed:

	Trinity	ACF/ARI
HPS 70W	1 plate	1 plate
TC128-Grade B	1 plate	1 plate

Using the conclusions from the previous testing on ASTM A841, the plates for head forming should not experience temperatures above 1300 degrees Fahrenheit. One specific recommendation is that this warm forming be done at 1175. The same sampling plan should be followed as before.

With this direction, the task force has tentatively concluded that the Northwestern steel will not be considered at this time and that the IPSCO material would certainly be evaluated for the shell rings once the head forming issue is resolved.

Welding

Assuming successful head forming and shell forming of these materials, the next step will be to evaluate the weldability of these materials. Experimentation in this area has already been concluded and reported by Bai[3] at the 2004 MS&T Conference. Certainly the tank car manufacturers themselves will want to make similar, independent evaluations.

TC128-Grade B Specification Adjustments

Higher Silicon

The current TC128-Grade B specification provides for Silicon to be 0.15% to 0.40% for plate thicknesses of ¾" and under while 0.15% to 0.50% Silicon is allowed for plates over ¾" thick. Trinity Industries evaluated a plate with Silicon marginally over the 0.40% maximum for ¾" thick and under. While Trinity reports no adverse conditions in manufacturing or metallurgical properties, the material tensile strength marginally exceeded the 101ksi upper tensile limit.

The task force has proposed to the AAR that a pilot study of 50 tank cars be conducted to study higher Silicon levels. The Silicon level should be higher in the 0.40% to 0.50% range with a target of 0.45%. The plan is detailed in the Appendix.

The evaluation of the material will include the following:

- welding procedure qualification tests
- tests shall include
  - -tensile strength
  - -side bends
  - -Charpy "V" notch at -30 degrees Fahrenheit
    - *base plate (transverse direction)
    - *heat affected zone (HAZ)
    - *weld metal
  - -periodic testing of head trimmings
- inspections of head knuckles and straight flanges on 1 in 5 heads
  - -dye penetrant (PT)
  - or -magnetic particle inspection (MT)
- spot check fillet welds
- cracking is unacceptable

The task force does not feel this will be problematic as other steels currently used in production have Silicon content at this level (see Table 2).

Silicon Content	
Material	Si
TC128-Grade B	-
≤3/4”	0.15 – 0.40%
>3/4”	0.15 – 0.50%
ASTM A516-Grade 70	0.15 – 0.40%

Table 2

Raising Tensile Strength

Steel specification TC128-Grade B is a little unusual as it not only sets the minimum tensile or ultimate strength, but also caps that strength at 101ksi. With the higher Silicon levels discussed in the previous section, higher tensile strength can be expected. If the maximum tensile strength of TC128-Grade B were increased it may not alter other specified properties, namely:

- impact strength (CVN)
- elongation

However, there is a lingering concern that the higher tensile strength leads to higher hardness, which generally reduces impact strength (CVN). Some quenching of the heads may occur during the head forming operation, again increasing strength at the expense of impact properties.

However, it has not been determined whether the minimum 15 ft-lb criteria will be compromised by the higher tensile strength. The argument was made that steels at the low end of the range in mill properties will not meet this 15 ft-lb requirement.

Conclusions

Tank car steels can be enhanced by using more modern steels which have improved properties to perform better at low temperatures as well as resist impacts that occur in railroad accidents involving tank cars. Three steels are particularly well suited to provide this enhancement:

1. High-strength, Low-carbon, Ferritic, Copper-Precipitation Strengthening Steels
2. X-70 line pipe steel
3. HPS 70W steel conforming to ASTM A709

The industry task force has decided to pursue head forming with the HPS type material to see if centerline segregation can be avoided, which will then produce CVN results which are not compromised. TC128-Grade B, the current standard, will be evaluated as a baseline comparison.

Increased Silicon in TC128-Grade B material for all thicknesses of tank car steel needs further evaluation through a 50 car pilot program. In this program base material, weld material, and heat affected zones will all be monitored as well as surface cracking at welds.

The unintended, but not unexpected, result of higher Silicon is greater strength. This increase in strength in some heats drives the tensile strength over the 101ksi limit. Debate is ongoing whether such an increase is actually deleterious to tank car steel performance.

APPENDIX

T95.7.3 Modifications to Current Steel Specifications – Task Force Proposal 10/10/2006

Discussion - Current Silicon content for plate thickness ¾" and under is 0.15% to 0.40% by weight while plates over ¾" thick are allowed 0.15% to 0.50%. High silicon samples tested OK at Trinity Industries with the only exception being that the upper tensile limit of 101 KSI was marginally exceeded. However, the sample was only marginally over the current maximum silicon content of 0.40%.

Further testing should be done with steel closer to the proposed 0.50% in order to fully understand the effects. Testing would essentially be standard procedure qualification testing, with spot CVN testing of heads or head trim during the respective production runs by the builders.

The Task Force recommends that the AAR Tank Car Committee grant waiver for each car builder to produce up to 50 cars using the higher silicon content steel.

50 CAR TEST PLAN FOR TANK CARS CONSTRUCTED OF Si MODIFIED TC128

1. Steel used to be in the 0.40-0.50% silicon range with 0.45% being the target goal.

2. Perform welding procedure qualification tests for all welding processes and materials to be used in the construction of the tanks. All testing to be in accordance with M-1002, Appendix W.

3. Procedure qualification tests are to include tensile strength specimens, side bends, and Charpy VEE Notch (CVN) samples tested at -30F for base plate, Heat Affected Zone (HAZ), and weld metal. CVN to be transverse to the rolling direction.

4. Perform periodic testing on head trim during production to assess consistency of properties. Tests are to include tensile strength specimens and CVN in the transverse direction.

5. Inspect by qualified method, dye penetrant (PT) or magnetic particle (MT), head knuckles and straight flanges on 1 in 5 heads. Inspection to be on both the inside and outside surfaces for a total of 2 square feet on each surface.

6. Spot check (using dye penetrant (PT) or magnetic particle (MT)) fillet welds on 1 in 5 cars, for a total length of 6 feet, to include at least 2 feet in the attachment of the head shoe reinforcing pad to the tank.

Points 5 and 6 are to assure no cracking problems in production. The Task Force does not feel this will be an issue since steel of this silicon content is currently being used.

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