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Structural Steels used for Dynamically Loaded Equipment

By

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Subject

Structural steels are used primarily for statically loaded structures. Civil and Structural Engineering standards have developed over the last 100 years that establish the requirements for this, and the testing needed to verify that the steel meets those requirements. When using structural steels in dynamically loaded structures and equipment, the requirements change. Using structural steels in on-road and off-road equipment, the designer must not only consider mechanical properties, but also the limits for the alloying elements. In SAE/AISI grades of steel the limits of the alloying elements are predetermined, and the designer only needs to specify the grade and condition or heat treatment. ASTM standards and specifications typically set minimum mechanical properties and maximum percentages for alloying elements. The designer must specify the lower limits of major alloying elements and the upper limits of the minor elements, to fit the uses of the equipment or structure.

The great latitude that is allowed by ASTM specifications for steels means that the end user needs to make decisions on which heat of steel to buy or use, requiring far more knowledge than just specification number and grade or type. The considerations that need to be taken into account are the fabrication methods and end use service conditions, such as minimum service temperature, and types of loading. If the operating temperature could be at minus 40^{o} F. or lower, having manganese content near the maximum limit is critical. For welded units, if fatigue is a critical factor, having sufficient aluminum, titanium, vanadium, and/or niobium to produce fine grained heat affected zones is critical. Again, for welded assemblies it is important to have the carbon content in the right range of 0.15 to 0.25 percent to avoid embrittlement of heat affected zones caused by lower or higher carbon.

This case study involves failed welded loader arms for a front end loader where ASTM structural steels were used for fabrication of a dynamically loaded assembly.

Chemical Analysis

The chemical analysis was done according to the following ASTM Specifications: E1019 for carbon and sulfur, and E415 for the other elements. The results of the chemical analysis are given in the table that follows.

Chemical Analysis of Loader Steel (Percent by Weight)				
Element	Loader 1	New	Loader 2	Specification*
Carbon	0.06	0.05	0.05	0.23 Max.
Manganese	0.78	0.69	0.31	1.35 Max.
Phosphorous	0.015	0.011	0.008	0.04 Max.
Sulfur	0.008	0.005	<0.005	0.04 Max.
Silicon	0.01	0.02	0.01	
Nickel	0.04	0.05	0.01	0.2 Max.
Chromium	0.02	0.02	0.03	0.15 Max.
Molybdenum	0.010	0.01	0.02	0.06 Max.
Copper	0.02	0.09	0.043	0.20 Max.
Aluminum	0.056	0.029	0.043	
Titanium	0.02	<0.005	<0.005	0.005 Min
Niobium	0.026	0.021	0.021	0.005 Min

*ASTM A1011/1011M – 05 High Strength Low Alloy Steel Grade 50

The Loader 1 steel and New Production steel are ASTM A1011/A1011M CS Type D steel, and the Loader 2 steel is ASTM A1011/A1011M DS Type A or B.

ASTM Specifications A715 and A607, have been replaced by ASTM A1011/A1011M, using the appropriate Structural Steel or High-Strength Low-Alloy Steel grade in the thickness that these samples were. Heavier gages are covered by ASTM A1018/A1018M

ASTM A568/A568M-07a **Standard Specification for Steel, Sheet, Carbon, Structural, and High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, General Requirements for,** Table X2.2 Standard Chemical Ranges and Limits, gives the ranges for alloying elements when maximum values are given in the specification. Given in information in Table X2.2, the range for carbon will be 0.16 to 0.23%, and the range for manganese will be 1.00 to 1.35%. Applying the Product Analysis Tolerances given in Table 2, the range for carbon is 0.14 to 0.23%, and the range for manganese is 0.95 to 1.35% for the samples tested. None of the steel tested met these requirements. The manganese and the carbon levels are too low.

Please note that ASTM steel specifications are very confusing, and cause buyers and engineers who are not thoroughly trained in their use a considerable amount of confusion. Another consideration is that all Referenced Documents in an ASTM specification apply to that specification.

The steel used for Loader 1 and the New Production will definitely perform better than the previous steels examined because of the higher manganese content, but they are not structural steels or high-strength low-alloy steels grade 50, because of the low carbon and manganese content compared to the specification.

Hardness Testing

The hardness testing was done according to ASTM E384, using a Knoop indenter and a 500 gram load. The results of the testing are given in the table that follows.

Hardness Test Data for Loader Steel					
Sample	Knoop	Std. Dev.	Maximum	Minimum	Hardness
4084	212	5.81	218	205	92.24 RB
New	197	5.22	206	193	89.06 RB
4085	184	5.22	192	178	86.04 RB

The hardness test data indicates that the steel is at least grade 50.

Metallographic Examination

The magnification shown for the photos is the magnification at which the photos were taken. The photos shown in this report may be smaller or larger in size than the originals.

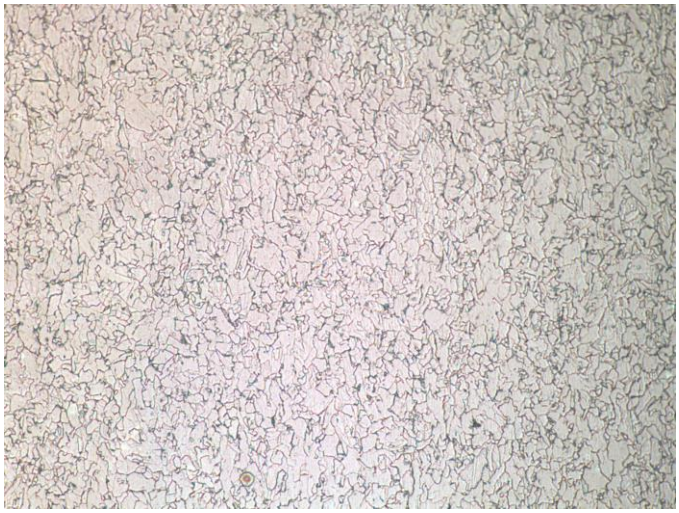

Figure 1 – 400X Microstructure of Loader 1

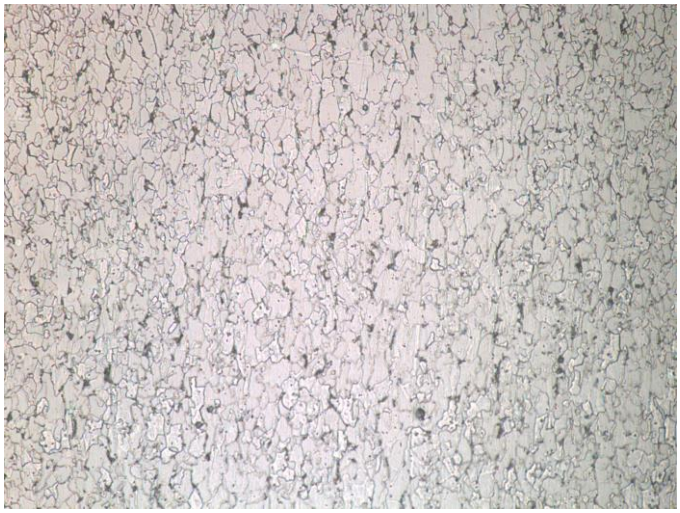

Figure 2 – 400X Microstructure of New Production

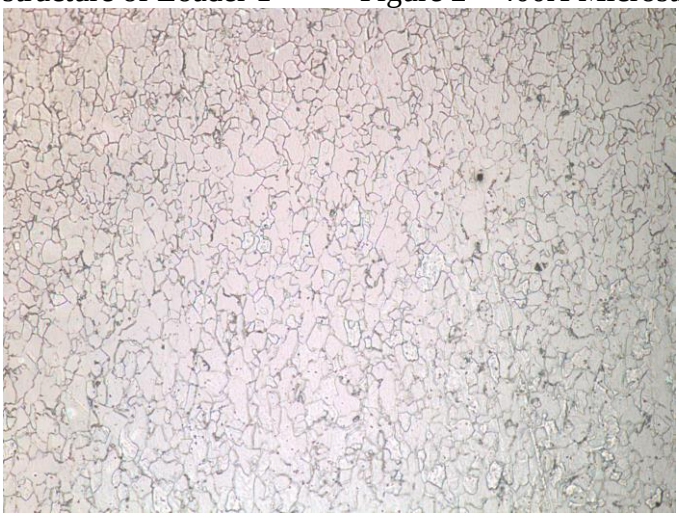

Figure 3 – 400X Microstructure of Loader 2

All three steels, Figures 1, 2, and 3, have a fine grain ferritic microstructure, which is consistent with their chemistry.

Conclusions

1. ASTM A715 and A607 are no longer valid specifications and have been succeeded by more general specifications, ASTM A1011/A1011M and A1018/A1018M.

2. ASTM A568/A568M provides ranges for alloying elements when maximum limits are given.

3. The steels used for the Loader 1 and New Production samples are improved over steel used for Loader 2, because of the higher manganese content, but the carbon content is too low.

4. The steel samples did not have the correct chemistry to be structural and/or high-strength low-alloy steel, according to ASTM A1011/A1011M.

5. The hardness indicates that the steel was at least a grade 50.

6. The Loader 1 and New Production steels are ASTM A1011/A1011M CS Type D steel, and the Loader 2 steel is ASTM A1011/A1011M DS Type A or B. Neither of these grades of steel are suitable for a welded dynamically loaded assembly.