# A Case Study of A 193 Grade B7 Used as a Teaching Tool

**Donald L. Goddard PhD PE**
**The University of Texas at Tyler**

Abstract

Utilization of A193 Grade B7 threaded rod as a case study in heat treatment of alloy steel is developed as a low cost, efficient approach to study standard material specifications, furnace operation, heat treatment, tensile properties, hardness, microstructure, and impact strength. By studying this 4140 type of material(commonly called "chrome-moly steel" ), basic concepts are examined and the students are familiarized with a common, high quality alloy that they can later use in practical applications.

## Introduction

Any student, having completed basic chemistry, would be ready for a first laboratory course in the realm of Materials Science and Mechanics of Materials, which might fall anywhere from the freshman to junior year, depending on the particular engineering curriculum. In such courses there is need for interrelated experiments which can give both depth and breadth of understanding which can be built upon in other classes, such as Machine Component Design. It is also very useful if such experiments should happen to be at the lower end of the cost range. A happy concurrence of these factors is to be found in threaded rod, which meets the ASTM Specification A 193 Grade B7[1]

| Designation | AISI-SAE 4140<br>UNS # G41400 | ASTM A 193<br>Gr B7 |
|---|---|---|
| Carbon | 0.38-0.43% | 0.37-0.49% |
| Manganese | 0.75-1.00% | 0.65-1.10% |
| Phosphorus (max) | 0.035% | 0.035% |
| Sulfur (max) | 0.040 % | 0.040% |
| Silicon | 0.15-0.35% | 0.15-0.35% |
| Chromium | 0.80-1.10% | 0.75-1.20% |
| Molybdenum | 0.15-0.25% | 0.15-0.25% |

**Table 1 Alloy composition comparison between AISI-SAE 4140 and ASTM A 193 Grade B7**

ASTM (American Society for Testing and Materials) specification A 193 is titled “Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service”. This is a specification of rather broad scope covering a variety of steels (over 50 grades and classes). However it is one grade, B7, that has proven particularly useful for fundamental teaching purposes. The specification is not only an alloy specification, but it also covers aspects of manufacturing and product form. That makes the specification in itself an interesting study in specifications for the students. The cost aspect associated with the B7 grade of material derives from the fact that one of the product forms for this grade is threaded rod. Commonly called “B7 rod” in the parlance of suppliers, this material grade of threaded rod represents a commonly used high strength rod stocked by bolt and screw vendors in virtually every small to large city in the US. It constitutes a high quality commodity which is stocked and sold in sufficient volume to benefit from economy of scale. The typical material cost as of this writing is about 40 cents per specimen. As a high quality commodity, it is also a product that engineering students may work with after graduation. A 193 grB7 steel is noted in the ASTM specification as a chromium-molybdenum steel and when compared to AISI-SAE compositions[2], it is seen to match up closely with 4140, being only slightly looser (mostly richer) in carbon, manganese, and chromium as shown in Table 1. As such, its properties are close enough to 4140 to be instructive as to the nature of that common designation of alloy.

Specimen Preparation

Although the rod is a high strength material, it still has reasonable machinability with common “carbide” tools. The threads are strong enough to be gripped directly on the thread in a lathe chuck without damaging the threads while turning the tensile specimens.

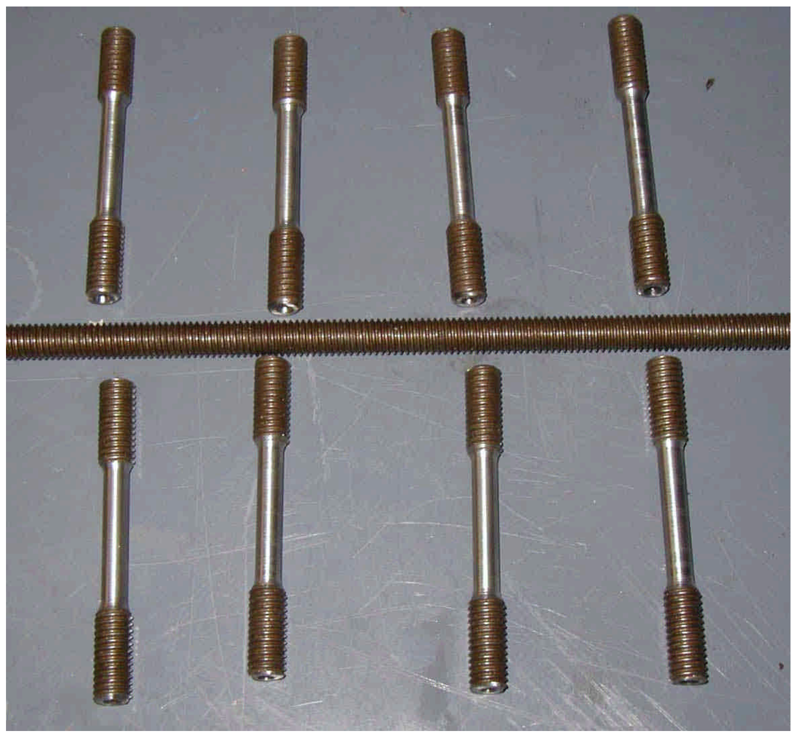

**Figure 1 The recommended two identical sets of specimens per student or team and a sample of the rod**

The Experimental Plan – Material Processing Phase

The scenario of laboratory experiments based on A 193 Grade B7 is as follows:

- From threaded rod stock (which comes standard in 36 inch lengths) tensile specimens are prepared. The specimens are made up in multiples of four for reasons which will soon become apparent (see Figure 1). Each experimenter or team should be allowed 2 sets to allow for sample defects or mishaps during testing.
- The specimens are “deeply” marked on the ends (typically with a pattern of saw cuts) so that the markings remain clear after heat treatment should oxidation occur.
- From each group of 4 specimens, one will be tensile tested “as is”.
- The remaining three go into the heat treating furnace where they are heated to a temperature that the students have identified (e.g. from carbon content and the Fe-Fe3C equilibrium diagram) that will fully austenitize them.

- Of the three specimens in the furnace, two are removed and immediately oil quenched. (As a variation other quenching media can be used to demonstrate the effects of varying the severity of quenching.)
- The specimen remaining in the furnace is allowed to slow cool with the furnace to assure a total annealing.
- One of the two quenched specimens is subsequently returned to the furnace to be tempered.

At this point the students are in possession of four variations of heat treatment of the same material: “as supplied”, annealed, quenched, quenched and tempered. Since the “as supplied” product is quenched and tempered, it offers some challenge to the students to see how closely they reproduce the original condition of the material. The challenge of replicating the original heat treatment also requires them to have studied the material to determine an acceptable austenitizing temperature; to discuss with the instructor the impact of an excessive austenitizing temperature on quenching; to search the specification to establish an appropriate tempering temperature; and to assess the size information in the specification as it applies to mechanical properties. Although it was said that the specimens are made up in groups of four, it is best to have multiple groups of four because sometimes there are problems in the lab and a specimen is spoiled and erratic results are common with the quenched specimen.

Occasionally the quenched specimens will show additional key points. The heat treated specimens should be protected against oxidation while in the furnace. It suffices to have a few charcoal briquettes present to scavenge the oxygen and bury the specimens in ash. However better protection is given by products such as “Keepbryte” coating, (Kasenit Company, Highland Mills, NY 10930). In either case, the specimens must be cleaned up to remove small amounts of scale or the coating. After this cleaning, they should be oiled. The oil provides an interesting extra in the case of the quenched and quenched and tempered specimens. The quenching done by the students often produces cracks in the specimen, particularly if the students select a severe quench. The previous oiling of the specimen allows oil to enter any such cracks. When the specimen breaks, the oil causes a distinct difference in coloration in the break, closely defining the portion of the rupture that was due to quenching and the portion due to loading.

The learning really starts for the students when the lab assignment is given.:

- They must find and examine the ASTM specification that they are working with.
- They must determine appropriate temperatures for austenitizing and tempering.
- They must familiarize themselves with furnace operation and programming.
- The next opportunity for learning takes place when the furnace is utilized
- They prepare or observe the preparation of materials for heat treatment
- They load or observe the loading of a heat treat furnace.
- They have an opportunity to observe the handling of materials at high temperatures.

The activities above generally take far less time than an entire lab period and are often an addendum to another lab activity. The subsequent work with this material will be the primary occupation of two or more laboratory sessions.

The Experimental Plan - Materials Assessment Phase

To this point, the students' lab and homework activities have been directed to researching the alloy specification, and planning and executing the heat treatment. They now have a certain "investment" in the experiment. This is motivational, and they will now have to find out the results of their efforts. The scenario of laboratory activities continues as follows:

- Tensile testing of the specimens: This includes the comparison of the ductility and "cup and cone" rupture of the annealed specimen which stands in stark contrast with the "square as a pool cue" fracture of the quenched specimen. The benefit accomplished by quenching and tempering becomes obvious from the high strength performance coupled with a reasonable degree of ductility, both of which are quite evident when the data is graphed.

  The fact that this material is easy to heat treat to more or less predictable results is what makes it valuable, but if tensile tests were the only thing obtained from this material, that would be only ordinary performance for laboratory education in materials. However there is more.

- Hardness testing: There may be some concern for accuracy of either hardness or tensile strength results obtained from the specimen shank. depending on the order of testing, as the hardness test may alter the results of the tensile test or vice versa. By using a metallurgical cut-off machine, it is possible to cut "buttons" suitable for hardness testing from the threaded ends of the tensile specimen after tensile testing is complete. These give good results for hardness testing and compare well with prediction formulas for ultimate and tensile strength such as:

  **Su = 3.45 BHN MPa** **Su = 500 BHN psi** **Equation 1**[3]

  and

  **Sy = 1.05 Su – 200 MPa** **Sy = 1.05 Su – 30,000 psi** **Equation 2**[4]

  Where **Su** and **Sy** are the ultimate and yield stresses respectively and **BHN** is the Brinell hardness number.

- Microscopic examination of the crystalline structure: After the tensile and hardness testing of the specimens, there remains yet one more laboratory activity. "Buttons" cut from the different heat treats of the specimens can be mounted and polished. In the case of ¼ inch tensile specimens, it is easy to mount the four different heat treatments in a single specimen mount. By using a clear mounting medium and being careful to maintain the identity of heat treatments of each button, the specimens may be assembled in the mounting mold and a small paper label can be embedded with the buttons. After grinding and polishing, a brief etch with 3% -5% nital etchant will bring out the various grain structures. A note of caution here, especially when using etchant as strong as 5%. The hardened specimens of the metal tend to etch faster than the annealed, and the application of the etchant should favor the etching of the annealed specimen. This can be a little tricky, since the total etching time will be mere seconds. The primary advantage of mounting all the specimens in the same mount is that during the laboratory session for examining the microstructure, other students may be examining other alloys studied during the semester. By mounting all A193 specimens in a single mount, other students can look at other alloys and share the results for comparison purposes.

- Impact testing: If one is so inclined, it is also possible to perform Charpy testing from the same material. However, if a standard 10mm square Charpy specimen is desired, then a minimum practical size threaded rod would be 11/16 or M17 in coarse or fine pitch. In the preparation of these specimens, the machining could be done prior to heat treatment without too much disruption of dimensions, except for the notch, which is critical.

## Conclusion

In a materials science or metallurgy laboratory class which has the customary facilities for tensile testing, Rockwell hardness testing, simple heat treatment, metallurgical microscopy, and optionally impact testing, doing a case study of an alloy such as A193 Grade B7, reaps several benefits. The students get to see multiple characteristics which make up the whole picture for a single alloy, and the various aspects of alloy selection become an integrated whole rather than separate abstract concepts. Depending on quantities of equipment available and class size, several laboratory sessions are linked into a continuous learning experiment. The time requirements are typically:

- material heat treatment – 1 lab sessions or part of a lab session
- mechanical properties testing – 1 or 2 lab sessions
- microscopic examination of crystalline structure – 1 or 2 lab sessions

Although many different alloys could be selected, the fact that A193 Grade B7 is available as both an alloy and threaded rod (a commodity product form), keeps the cost low and the availability is excellent. This alloy is essentially the same as AISI-SAE 4140 which is readily available in multiple forms of stock and heat treats, and the composition is so close that the students obtain a practical, useful familiarity with a common high-quality engineering metal alloy. So long as the students are informed from the start that there will be multiple continuing labs with this material, they have a stake in maintaining good continuity. The students are themselves are responsible for the properties of some of the specimens, and have an industrial standard to compare their work to. This leads them to have a personal investment in the specimens and proves very motivational.

## Bibliography

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3. Juvinal and Marshek, Fundamentals of Machine Component Design, 3rd ed., John Wiley & Sons, (c)2000, pg 90
4. ibid, pg 91

## Biography

Dr. Goddard teaches machine design and materials courses at The University of Texas, Tyler. His university teaching experience totals of 20 years, preceded by 13 years of industrial experience in nuclear power generation equipment design. His PhD degree is from the University of Nebraska. He has subsequently taught at the University of North Dakota and The University of Texas at Tyler.