Multiple strength tests of industrial fasteners as an educational case study

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Abstract The advantages and challenges of the study of fastener materials is investigated as a teaching tool. The importance of the different types of material strength are investigated in a readily available, highly variable, low cost, ubiquitous, critical machine component.

Keywords impact testing; bolts; threaded fasteners; laboratory experiments; materials science

Introduction

In the never-ending quest to keep laboratory experiments relevant, interesting, and within budget, the investigation of the strength of fastener materials has much to offer. It has not been that long since the United States had to enact strict laws pertaining to the head markings of bolts and cap screws, because unscrupulous manufacturers and importers had marked low-strength bolts as high grade. Machine designs can succeed or fail simply because bolts and screws do not perform properly, and the results of those failures can be catastrophic. It is not hard to convince students of the importance of these matters, and therein lies one of the great advantages of doing a case study of threaded fasteners as a special class of machine components.

Another key advantage utilizing fasteners is that they are readily available in small quantities at moderate cost. If one wishes to study a particular material and needs a few tensile or Charpy specimens, the standard unit of material is typically a 12–20-foot or 3–6-meter bar accompanied by excessive minimum-order costs and shipping, or, alternatively, excessively high costs for cutting charges and the prices charged by ‘small order’ specialty sources. In comparison, it is a simple matter to go to a local fastener outlet and pick a few of each of several different grades of fasteners (Fig. 1), many of which have the specification, grade, or nominal strength stamped right into the head. The fasteners in this case do have the characteristic that they are a manufactured product with typical levels of industrial quality control and as such are not ‘precise laboratory specimens’, which may or may not perform as real products in the real industrial world.

It would be remiss to fail to note any drawbacks to utilizing specimens cut from commercial fasteners and there is one in particular, which pertains to the high-strength fasteners. The machinability of a high-strength fastener may leave much to be desired. These can be very tough and hard, so that the cutting of threads of precise notches, as in Charpy specimens, can be somewhat challenging. The use of roughing passes and good carbide tools is often the only practical approach, and success

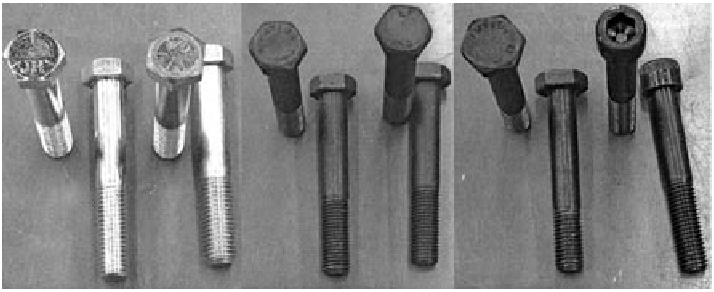

Fig. 1 *Selection of bolts illustrative of the ready availability of a variety of technically important, clearly identified materials for testing. From left to right: Grade 5, Grade 8, Metric 8.8, Metric 10.9, A325, A574 socket head.*

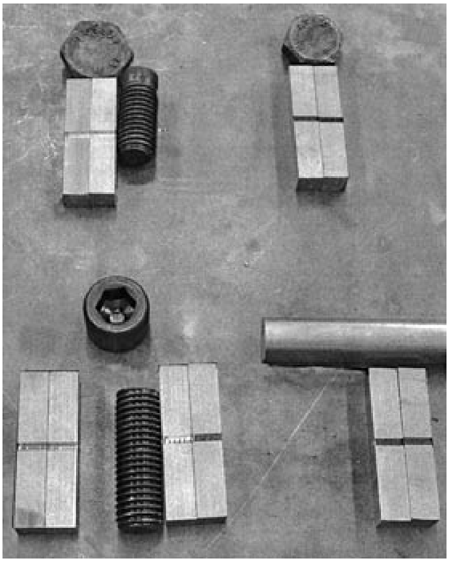

Fig. 2 *A selection of Charpy impact specimens derived from bolting materials. Clockwise from lower right: 1018 cold rolled for reference, A574 socket head cap screw as supplied and annealed, A325 structural steel fastener, 8.8 metric hex cap screw.*

should not be expected on the first attempt unless a competent machinist is available. Samples of Charpy specimens cut from typical fastener materials are shown in Fig. 2.

The teaching exercise

At the University of Texas at Tyler Mechanical Engineering Department, the testing of bolting materials as a teaching exercise has been a multi-semester activity. This multi-semester approach offers the advantage of exposing the students to the concept of being just one link in the experimental investigative process. The students must utilize the data of other students who have previously worked on project and must prepare their work well enough so that it can be used by subsequent students. It removes some of the attitude of 'I am just doing this for the teacher in this class this semester' and puts the work of the student into a larger perspective.

In our experience, the most profoundly driven-home point comes when the students have tested the tensile strength of fastener materials and have seen that higher-grade bolts have higher strengths, not to mention higher cost, and then are shocked to find that the highest-strength bolts are outperformed by almost every other class of bolt when it comes to impact strength. It is not a great exaggeration to say that their faces fall like the pendulum on the impact tester when they see the pitiful performance of some of these materials in impact.

The types of testing that are most relevant for bolting materials and expedient in a classroom setting are discussed under separate headings, below.

Hardness testing

This is the simplest and quickest of tests to run and requires little or no preparation of the specimen. The hardness test can be run on a Rockwell testing machine and the ultimate and tensile strengths can be readily estimated. It may also be instructive to cut a 'button' from the shank or threads of a larger bolt and then execute hardness tests at various radii to see if a hardness gradient can be detected or any additional hardness in the vicinity of rolled threads.

Tensile testing

This is probably the most relevant test with respect to fastener grade, since this is the parameter most directly reflected by the grade. Indeed, the common metric markings of bolts, such as 12.9 or 10.9 or 8.8, are simply designating the nominal ultimate tensile stress, in hundreds of megapascals, by the number before the 'point', and the ratio of the yield stress to ultimate stress, by the number after the 'point' (e.g. 8.8 indicating that the nominal ultimate stress is 800 megapascals, and a yield stress that is 8/10 of that, or 640 megapascals) [1].

Charpy or Izod impact testing

This testing is extremely important to the student's education because the hardness and tensile tests both correlate well with increasing fastener grade and with this testing the very different nature of impact strength becomes blatantly obvious (see Fig. 3, below). The notion that a lower-grade bolt is stronger in some aspect becomes real and the notion that there may need to be a compromise to get the best combination of strengths comes to the fore.

Microstructure examination

In a materials science setting, there is often a need for appropriate specimens to examine. The remnants of tensile and impact testing of bolting materials as noted above can provide a plentitude of specimens for which the microstructure can be

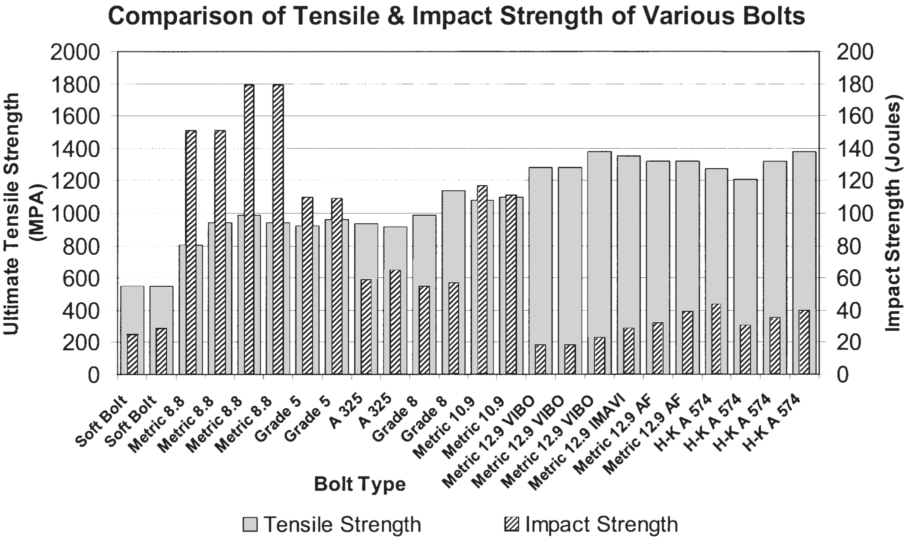

Fig. 3 *Results of multiple semesters of fastener tests.*

examined. Since a single well prepared specimen can be used to enlighten the entire class, various aspects shown by different alloys can be prepared by other students and shared. Not all students need prepare the same specimens. In small classes, in the interests of time, different materials which will etch similarly can be embedded in the same specimen mount and if a clear acrylic mount is used, it is fairly easy to embed a label clearly identifying the various specimens, thereby saving considerable mounting, grinding, and polishing time.

Practical results

The results of multiple semesters and many tests are reflected in the bar graph in Fig. 3. The disconnection between high tensile strength and high impact strength stands out starkly and the effect on both of these of the heat treatment of the fasteners is shown by the presence of some annealed specimens. The fact that the tensile strength of some moderately high-strength bolts is not all that far behind the strength of the highest-strength bolts (compare Grade 5 and 10.9 bolts to the 12.9 and A574 socket head cap screws [2]) is readily noticed by the students. At the same time, they can easily see that when the impact performance is examined, the former perform well with respect to impact while the latter perform poorly (if not miserably).

An additional area of 'practical' learning that takes place is the familiarization of the students with various US and metric bolt head marking systems. Such practical knowledge is often neglected in our current, highly theoretical engineering curricula.

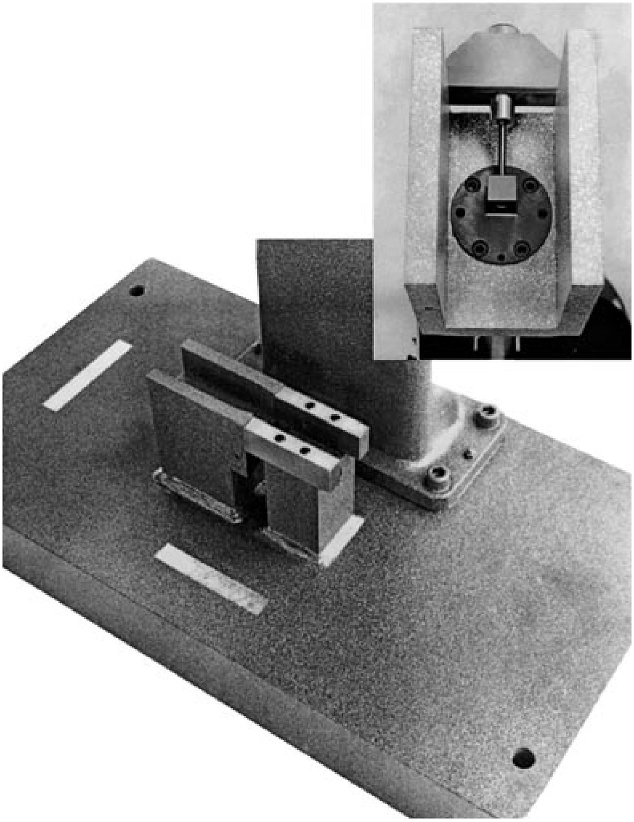

Fig. 4 *Tinius Olsen tensile impact apparatus on a series 84 impact tester.*

Areas to be developed

Some areas are yet to be developed in this case study of strengths of fasteners.

Cost

Given the degree of business-related emphasis on the economic viability of products, the cost advantages combined with the vastly greater impact strength of the moderately high-strength bolts becomes a most interesting area.

Appropriate impact testing

It can be argued that the type of impact experienced by a threaded fastener may not be well modeled by either Charpy or Izod impact tests. An interesting alternative is offered by the Tinius Olsen company [3] for its series 84 impact testers. The device replaces the typical Charpy or Izod tup in the pendulum with a special tensile impact tup. The apparatus is shown in Fig. 4. This type of impact testing may prove to be even more appropriate and illuminating for the students. Size limitations for the fastener need to be assessed as well as the issues of fastener length, because long fasteners can absorb more energy, and tensile preload on the fastener at the time of testing and utilization. At least for small sizes of cap screws, it should be possible to actually test a screw as manufactured. In this way, the interplay of the screw material properties with the geometry of the screw can be seen as well. For instance, the sensitivity of the screw material to the stress concentration at the root of the thread and the head–shank junction and various aspects of the radii used at these locations can be examined.

Notes

[1] *Machinery's Handbook*, 26th edn (Industrial Press, 2000), p. 1560, gives this as the first number being 'one tenth the minimum tensile strength measured in kgf/mm^2'; this is essentially the same value as noted above and has also been expressed as thousands of kgf/cm^2.

[2] *ASTM Annual Book of Standards, Volume 15.08, Fasteners*: Designation A 574M-98 Standard Specification for Alloy Steel Socket-Head Cap Screws [Metric]. (This revision of the specification may be found in various years of the *Annual Book of Standards*.)

[3] Tinius Olsen Testing Machine Co. Inc., Easton Road, PO Box 429, Willow Grove, PA, 19090-0429, (215) 675-710, advertising brochure TO6051-10m-995-PCG.