Standards Topics

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Hydrogen Embrittlement Revisited: Part I

I have received several letters concerning the February 1995 "Standards Topics" column, which listed the various standards concerning hydrogen embrittlement. Basically, I have been asked to elaborate on the standards—how to use them and, in particular, how to bring them into current contracts.

Removing Residual Stress

In the finishing of high-strength steels, one of the first considerations has to be the removal of any tensile stress introduced into the part during fabrication operations. Typical operations that may introduce stress into the part are:

- Cold forming
- Cold straightening
- Grinding
- Machining
- Severe deformation

Removal or reduction of induced stress is accomplished by a low-temperature baking operation (at least 50 °C below the alloy tempering temperature). The length of time of the baking operation varies with the tensile strength of the steel and, of course, the timing of the bake does not begin until the part first reaches the baking temperature.

The removal or reduction of residual stresses is necessary so that mobile hydrogen (atomic hydrogen that is free to migrate) will not migrate toward these areas of high stress. The hydrogen may result from surface rusting, caused by local humidity conditions, or might be generated during the cleaning and preparation process. As the hydrogen gathers at the high-stress areas, it may approach or even reach the critical hydrogen concentration, where micro-cracks may initiate. Once these cracks initiate, they cannot be removed or repaired by further baking. They are permanent, and permanently reduce the strength of the part.

Classes of Stress Relief

ASTM B849-ISO/DIS 9587, *Pretreatments of Iron or Steel for Reducing the Risk of Hydrogen Embrittlement*, identifies nine standardized stress relief classes. The classes, SR-0 through SR-8, are intended to be called out on part drawings. During the initial development of the document, the working group identified 34 different stress relief treatments in commercial use. With minor variations, treatments centered on four tensile-strength levels: Those >1800 MPa; 1400–1800 MPa; 1000–1400 MPa; and surface-hardened parts <1400 MPa. To these four classes, we added a "Class 0" for users who wish to exempt their parts from stress relief treatment.

The baking temperature, with the exception of surface-hardened parts, ranged from 177–230 °C. Historically, the first stress relief treatment of record called for a bake of 375 °F ± 25 °F. (The ± 25-degree tolerance represents the actual tolerance of commercial baking ovens.) Translated into SI metric, that would be 190.5 °C ± 13.9 °C, or 176.6–204.4 °C. (*Note: Fractional temperatures used here are direct conversions from Fahrenheit, for the convenience of readers who may want to convert back.*)

Additional stress relief treatments were subsequently developed because, although this historical treatment worked well for many parts, it did not work for *all* parts. Experimentation and empirical results gradually raised the treatment temperature from 190.5 °C ± 13.9 °C to 215 °C ± 13.9 °C, or 201.1–228.9 °C, which was rounded out to 200–230 °C. For tempered steels, there is a caveat that the maximum temperature of baking shall be at least 50 °C below the tempering temperature.

As in every ASTM standard, any negative votes must be resolved before a draft standard can move forward for formal issue. In the case of B849, the stress relief document, the representative of a large chromium plater voted negative on the proposed standard because it did not include classes to describe the stress relief treatments contained in QQ-C-320 and other U.S. government documents.

Another objection was the inclusion of a "Class SR-0" for purchasers to specify that they did not want stress relief treatment applied to their parts. The negative voter's opinion was that, as far as chromium plating was concerned, no one—including the purchaser—had the right to omit stress relief. When it was pointed out that a number of steel alloys, such as the high-nickel alloys, were not subject to hydrogen embrittlement and did not require the baking treatment, the negative voter was unswayed. The individual readily admitted no knowledge of hydrogen embrittlement, but maintained the objection.

Time after time, compromises agreed in committee would receive a negative vote. Appeals to reason and logic were to no avail. After four years, we finally gave up and added four classes to describe the additional treatments, but retained the "Class SR-0." (The negative voter fortunately overlooked this item on the final ballot, and the standard was adopted.)

Shot-Peening

The second consideration in the finishing of high-strength steels is the application of shot-peening. Shot-peening is a process for cold-working surfaces by bombarding the items' surfaces with solid, spherical shot at a relatively high velocity. This process induces residual compressive stresses in the surface and near-surface layers on the part, through which hydrogen does not readily diffuse. It has been found that the shot-peening process will increase the fatigue life of parts subject to bending or torsional stresses, and will improve resistance to stress-corrosion cracking. ASTM B851-ISO/DIS 12686, *Automated Controlled Shot Peening of Metallic Articles Prior to Nickel, Autocatalytic Nickel, or Chromium Plating, or as Final Finish*, is identical to U.S. and ISO specifications, providing the necessary ordering information to implement this process.

Minimizing Hydrogen's Effects

The third consideration in the finishing of high-strength steels is the need to minimize the effects of any hydrogen that may have been adsorbed by the part during the cleaning, preparation or coating process. Note that I did not write "electroplating" process, because any coating process that has a step involving water or water solutions has the potential of providing hydrogen that may be adsorbed by the part.

ASTM B850-ISO/DIS 9588, *Post-Coating Treatments of Iron or Steel for Reducing the Risk of Hydrogen Embrittlement*, identifies 18 standardized embrittlement relief classes. The classes, ER-0 through ER-17, are intended to be called out on part drawings. During the initial development of the document, the working group identified 61 different hydrogen embrittlement relief treatments in commercial use. With minor variations, treatments centered on eight tensile-strength levels. These were strengths >1000 MPa, in increments of 100 MPa up to 1800 MPa. A class was provided for unpeened items and for items coated with electroplated engineering chromium. Additional classes for surface-hardened parts and parts >25 mm in thickness with threads or sharp notches are included, as well as a class for those purchasers who wish to exempt their parts from treatment.

Clause 4.3 of both B849 and B850 requires, when the purchaser does not specify the treatment class to be used, that the respective SR-1 or ER-1 treatments be the default treatments the electroplater, supplier or processor shall use. Note 4 of both documents explains that the electroplater, supplier or processor is not normally in possession of the information necessary to determine and select the correct treatment to be applied. The note further explains that it is in the purchaser's interest that the part designer, manufacturing engineer, or other technically qualified individual specify the treatment class on the part drawing.

Once again, the negative-voting chromium plater delayed matters until we agreed to add six classes to describe the requirements of the antiquated U.S. government standards. If I have been overly hard on our negative voter, I apologize. In retrospect, he made valuable contributions. First, he made it clearly evident that, in the consensus standards process, every opinion will be heard and that the "little guy" can prevail. And second, he has provided an opportunity to point out that, as they are devised, new and better treatments can be added to the standards.

Future columns will cover test methods for hydrogen embrittlement, methods that are still under development, and areas where further work is needed. ❑