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Apple Strength Issues

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Data Analysis:
Strength of the apple parts has been noticed to decrease, especially those installed by the new induction heating system since the LEP campaign started. Fig. 1 shows the ultimate tensile strength (UTS), yield strength (YS), and elongation of the installed or installation-simulated apples on various systems. One can clearly see the mean values of UTS and YS of the post-LEP parts decreased by about 8 ksi and 6 ksi respectively from those of the pre-LEP parts. The slight increase in elongation seen in Fig.1 can be understood from the weak inverse relationship between the strength and elongation in metals. Fig.2 shows the weak correlation between the YS and elongation of the parts listed in Fig. 1.

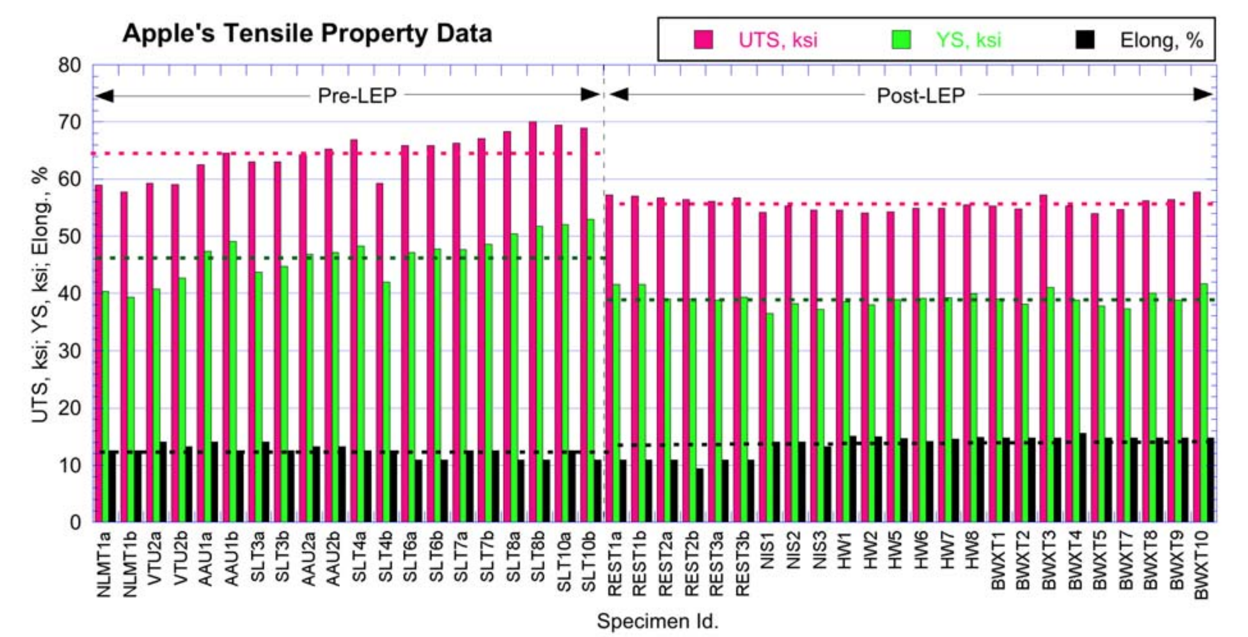

Fig. 1 Distribution of ultimate tensile strength (UTS), yield strength (YS), and elongation (Elong.) of apples. Reference 1.

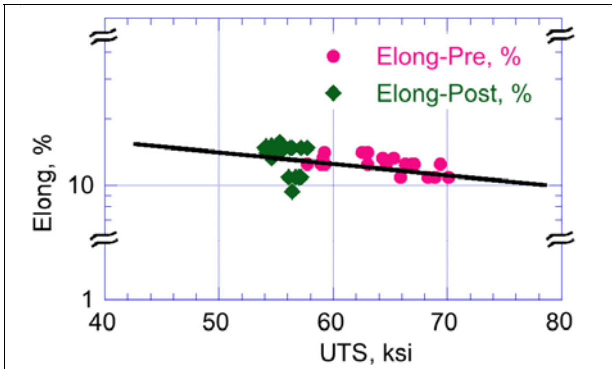

Fig. 2. A weak but clear correlation between yield strength (and tensile strength) is visible both in pre and post LEP materials

Strength data listed in Figure 1 were re-plotted as histograms in Figs. 3 and 4. Figs. 3a and 4a show histograms of all UTS and YS data. Figs. 3b and 4b shows histograms of pre-LEP data and

Figs. 3c and 4c of post-LEP data. Data on statistical scatter of tensile strengths have been rarely published by material suppliers. Instead, only the minimum “guaranteed” strength data are typically presented. An example of strength distribution of aluminum 7075-T6 sheet material, listed in Fig. 5, show that its scatter width of both UTS and YS for a single sheet can be about 6 ksi and for multi-lot scatter can be as large as 11 ksi even though the sheets have been produced through well-controlled manufacturing process.

By approximating the histograms shown in Figs. 3 and 4 by a Gaussian or similar type of distribution curves, one can plausibly see the strength reductions in the later or more recent apples. The pre-LEP data in Figs. 3b and 4b show wider scatter than the post-LEP data in Figs. 3c and 4c and seem to follow the binomial distribution of strength indicating that the apples might have been made from two different lots of material, either from two different vendors or from two different melts of perhaps slightly different chemical composition by a single vendor. The post-LEP apples seem to have been from a single batch of material. The pre-LEP apples of the weak strength and the post-LEP apples with even weaker strength could have been made of the same batch of material, and the small strength differential might be due to the difference in the induction heating system. If the pre-LEP apples with the lower strength and the post LEP apples are made from the same batch of material, their combined scatter of strength data would be wider and can be understood as a result of the additional processing steps of stress relief and induction heating as discussed below.

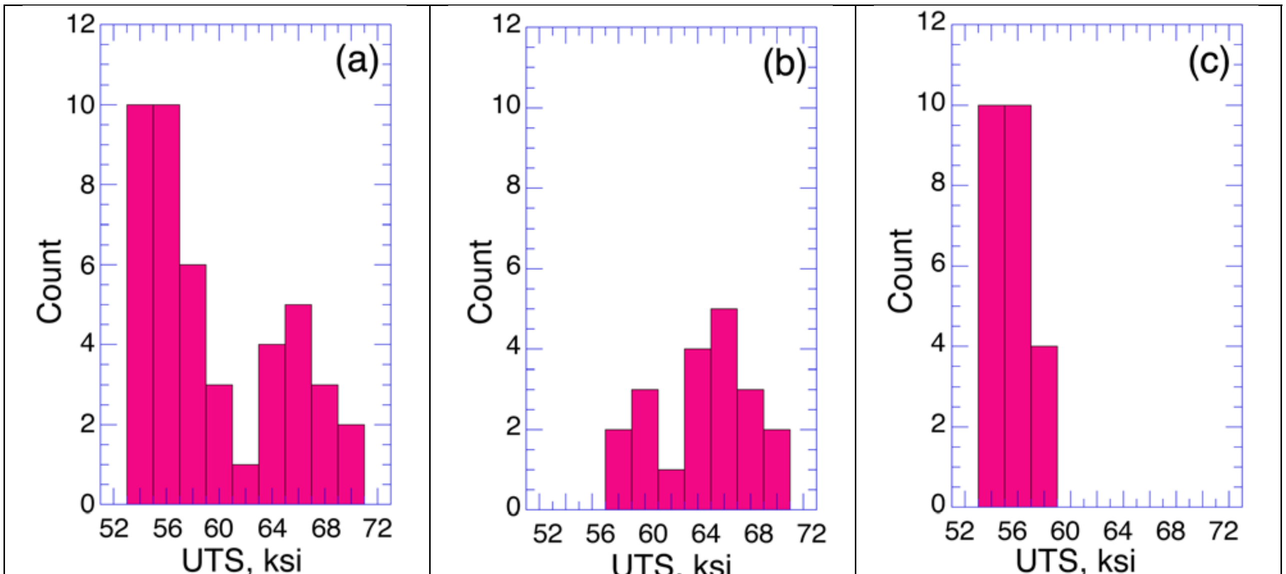

Fig. 3. UTS histograms, (a) for all data, (b) for all pre-LEP data, and (c) for all post-LEP data

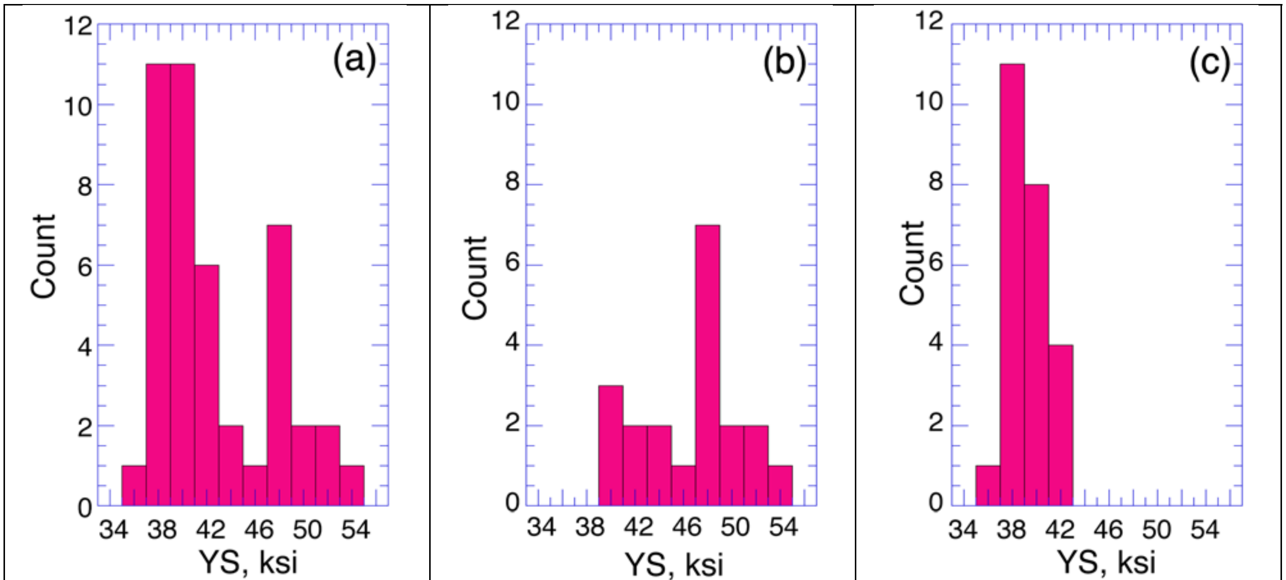

Fig. 4. US histograms, (a) for all data, (b) for all pre-LEP data, and (c) for all post-LEP data

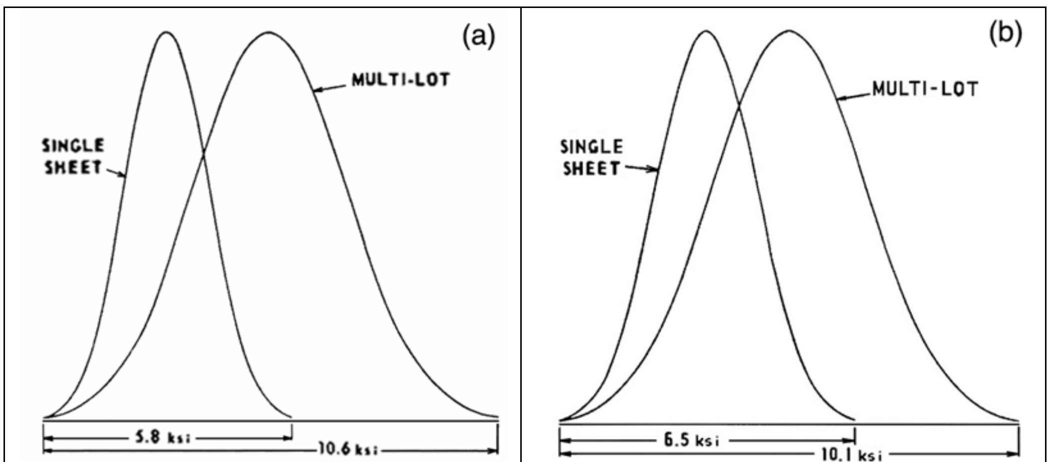

Fig. 5. Scatter in the strength data of AlC (aluminum clad) 7075-T6 alloy. (a) for the ultimate tensile strength and (b) for the yield strength

Discussion:

Apples are machined from a forged Al 7050-T73511 tube with fine microstructure and then further processed for stress relief by furnace-heating and induction-heating installation following rather well-established procedures. The starting tube material has gone through an elaborated processing procedure including heavy forging and extrusion, solid solution and double aging heat treatment with intermediate stretching. Microstructure in the tube consists of extremely fine GP zones of diameter of a few nm and submicron-sized η' phases. These two phases are thermodynamically meta-stable and GP zones will transform to η' and η' to the stable η if they are exposed to higher temperature and/or held for a prolonged period. The yield and tensile strengths are determined by the volume fractions and particle sizes of the two meta-stable phases. As the over aging proceeds, the volume fractions of the strengthening phases decrease and are replaced by the stable phase with increasing particle size leading to the loss of strength. Thus the additional steps end up with highly overage coarse microstructure and each additional step will increase the scatter in the strength properties.

Four issues pertaining to the strength decrease in the recent apples may be reviewed. The first issue can be the chemical composition of the material. The chemistry of the recent material is known but the old material’s composition is not listed or not accessible to this report. Chemistry difference in the important alloying elements could explain partially the strength reduction. The second issue could be the stress relieving heat treatment using a heat-treating furnace. It is not clear whether the number of parts, heating time, holding time, cooling time and/or cooling method used in the stress relief heat treatment have been kept constant and well controlled. These parameters, if not controlled closely, may exacerbate the over aging effect and lead to the wider strength distribution.

The third issue can be the temperature measurement during the installation. Figure 6 shows an example of comparison of the heating curves between the old and new induction heating practices. Figure 6(a) shows the heating curves from three thermocouples in the old installation facility as recorded September, 1986, and Fig 6(b) the heating curves from three thermocouples in the new facility as recorded in July, 2002. In Fig. 6(c), the heating curves listed in Figs. 6(a) and (b) are overlapped on the same scales. Fig. 6(c) shows the actual heating time is shorter in the new installation procedure than in the old procedure. The total time duration is shorter in the new induction heating procedure and the strength should be higher because of the shorter time for over aging. However the measured tensile and yield strengths are slightly lower after the induction heating by the new procedure as shown in Fig. 1. The lower strength can only be the results of overheating either at temperature higher than the nominal temperature or extended holding time at the nominal temperature. Thus one may think it is possible that the temperature reading may under-represent the real temperature experienced by the material if the chemical composition is the same and the stress-relief step is performed exactly identical.

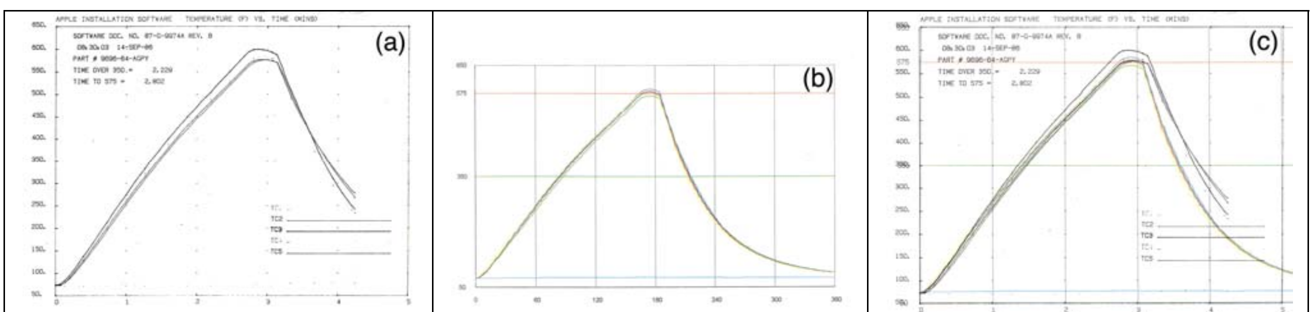

Fig. 6. Comparison of heating curves between the old (a) and new (b) induction heating methods and the overlapping of the old and new curves on the same scale as shown in (c).

The main difference in the old and new induction heating system is the induction coil configurations. In the old system, the heating coil is a vertical loop and the apple with a much larger diameter loops through the heating coil and the oscillating current in the coil induces electric current flowing along the apple ring. In the new system, the heating coil is concentric with the apple and of a larger diameter than that of the apple and the oscillating current in the coil induces current in the direction transverse to the apple ring circumference. Unless the thermocouple configurations are adjusted, the temperature readings may not be the same as in the old system. The possibility of the under-representing the actual temperatures should be checked further by detailed re-visit of the thermocouple settings and related measuring circuitry.

The fourth issue may be that the wider scatter in the UTS and YS data of the recent batch of material and the slightly lower strengths observed in the apples installed using the new induction heating facility may still fall within the scatter band. It is highly unusual that this aluminum alloy is used in a highly over aged condition. As discussed above, the scatter in the strength would be far wider in the over aged condition than in the optimally heat treated condition. However, to increase the safety margin of the apple parts, the wide scatter in the strength values should be narrowed toward the higher end of the strength scale. A clear quantitative correlation between the composition, processing history and strength is necessary first before improving strength and scatter.

To establish a clear correlation, all the relevant data should be collected and additional analyses may have to be performed. The relevant data items are: i) chemical composition of all batches of material, ii) strength data of the initial material and strength data after the stress relief of all batches, and iii) all data on stress relief procedure. Additional analyses required are the micro structural characterization of volume fractions of the strengthening precipitates, grain sizes, inclusions and constituent particles mostly by X-ray diffraction and SEM metallography. Additional tensile test may be required, too.

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