The Los Angeles Silhouette Club

Toughness Of Lead-Tin-Antimony Alloys

By Geoff Chamberlain

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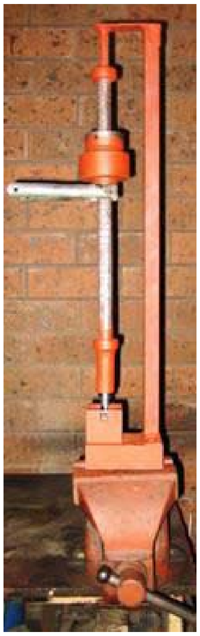
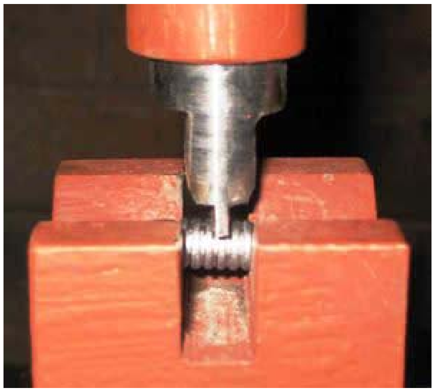
When choosing which metal to use for a specific application, physical properties such as strength, hardness, ductility and toughness are often important. Toughness, defined as the ability to withstand shock loading, is commonly determined by the Charpy test (ASTM E23). This involves a pendulum breaking a standard specimen: the pendulum's loss of energy from before-impact to after-impact is the toughness measurement.

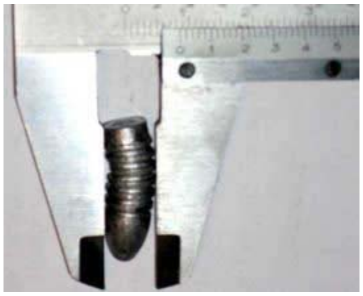
Toughness is a critical characteristic used by the military to compare the impact performance of specimens of armor plate. It has the potential to be similarly useful for comparing the expected behavior of bullets cast from various lead-tin-antimony alloys when they strike animals. Because I found little actual data on the toughness of these alloys, I decided to investigate the matter experimentally. In most respects the Charpy test was suitable for my experiments but I wanted to obtain a direct indication of specimen ductility. While ductility can be inferred from the 'instrumented' Charpy test it is not indicated by the simple mechanical version, and the instrumented version was beyond my intended scope. I therefore departed somewhat from the Charpy concept and chose to deform my specimens by a standard amount instead of just fracturing them. This still gave me a measurement of the deformation-energy required, but also enabled me to grade specimens as ductile if they deformed without cracking, intermediate if they cracked but retained considerable strength, and brittle if they fractured before reaching the standard amount of deformation.





I developed a simple drop test device, shown in the first photograph. The large cast iron weight (partly-elevated and supported by a spring-clamp in the picture) is raised a suitable distance up the graduated slide then released to fall and strike the chisel, which rests against the side of a test specimen placed on an interrupted V block. The specimen, V block and chisel are shown in more detail in the picture #2. The specimens were bullets cast in a Lyman 311466 mould: a standard commercial bullet mould readily available to other experimenters, and which easily produces large numbers of physically-identical cast specimens of suitable proportions for testing. Consistent axial location of each specimen was achieved by resting the shoulder at the end of the gas check rebate against the edge of the gap in the supporting V-block. This gap was 10 mm wide. The chisel tip was flat and 2.5 mm wide. The mass of the drop-weight could be varied between 1.5 and 6.5 kg (1.5 shown in photograph), and the drop-height could be varied from zero to 30 cm. The toughness measurement was simply equal to the potential energy of the weight when suspended at its drop-height, since all of this energy was subsequently converted to kinetic energy then absorbed in deforming the specimen. The effective anvil mass was maximized by clamping the test device in a large industrial vice bolted to a 16 mm steel bench-top.

The standard amount of deformation I applied is shown in the photograph at left (picture #3). Drop-height and -mass were adjusted to give an 8.5 mm dimension across each specimen after deformation, unless fracture occurred first. The specimen shown in the caliper was classified as ductile. The second picture shows an intermediate specimen, which developed a tensile crack directly opposite the chisel. The third picture shows some brittle failures: when deformed to the 8.5 mm dimension the two parts were almost separated, and could have been broken by finger pressure.



I investigated the effects of three variables on alloy toughness: heat-treatment, percentage of antimony, and having a low tin-to-antimony ratio versus equal amounts of tin and antimony in the alloy. Heat-treatment consisted of holding a sample for one hour at a selected temperature between 175 and 240 degrees Celsius, then water-quenching. The first experiment involved a wheel-weight alloy of about 0.2% tin and 2% antimony, remainder lead with a minor amount of arsenic. The alloys will be described by their percentages of tin and of antimony, so I will refer to this as 0.2/2 alloy. Physical analysis was not available, so all alloys were identified indirectly by simultaneous use of three methods: calculation based on their ingredients; the alloy's liquidus temperature; and the hardness of air-cooled samples. In the absence of physical analysis, reported compositions should be considered approximate. All specimens of each alloy were cast in a single batch from a single pot of alloy. For each hardness level a sample comprising fifteen specimens was aged at ambient temperature for two weeks after casting or heat-treating, before testing. Five specimens from each sample were hardness-tested using a Lee tester, and as many of the other ten specimens as necessary were impact-tested at various energy levels until the required deformation measurement was achieved.

The effect of heat-treatment on 0.2/2 alloy is shown by the chart at right (chart 1). In all of the charts that follow ductile results are shown as circles, intermediate results as triangles, and brittle results as squares. The lowest-hardness sample was always air-cooled and the highest-hardness sample was as hard as I could make that alloy by simple oven heat-treatment and water-quenching. Toughness initially increased with increasing hardness, but a peak was reached at about 19 BHN and beyond this hardness, toughness declined.

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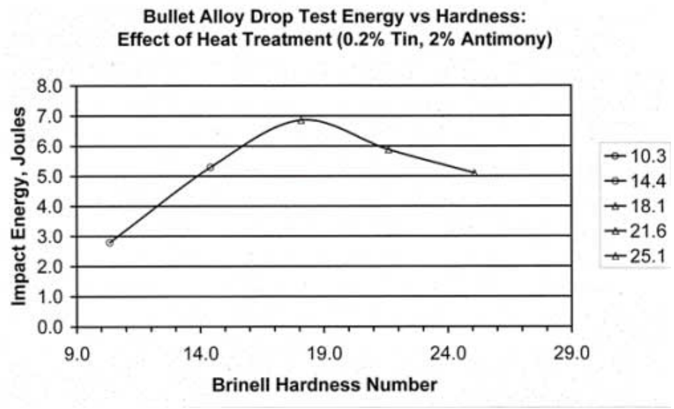

Chart 1

In the second experiment four fairly commonplace low-tin bullet-casting alloys having different antimony contents (0.2/2, 0.9/4, 2/6 and 2/13) were compared. Results are shown on chart #2.

The greatest peak toughness, 7.5 * Joules, was achieved by the 4% antimony alloy. Both 2% and 6% antimony alloys had less peak toughness than this, and the 13% antimony alloy had little toughness regardless of heat-treatment. In all cases peak toughness seemed to occur at a hardness close to 19 BHN.

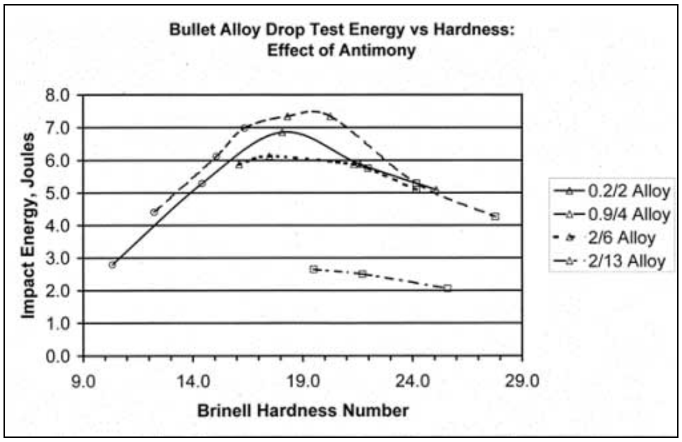

Chart 2

For the third experiment three of the four low-tin alloys were compared with their pseudo-binary equivalents. A pseudo-binary alloy of lead-tin-antimony has equal percentages of tin and antimony. In such alloys substantially all of the tin and antimony are expected to combine to form the compound Sb Sn, so the alloy effectively is binary, or consists of only two substances: lead and Sb Sn (ignoring minor amounts of arsenic that may be present). The well-known Lyman No. 2 alloy, which would be called 5/5 under the notation used here, is pseudo-binary.

The first comparison was between 0.2/2 and 2/2 alloys. Results are shown in chart #3.

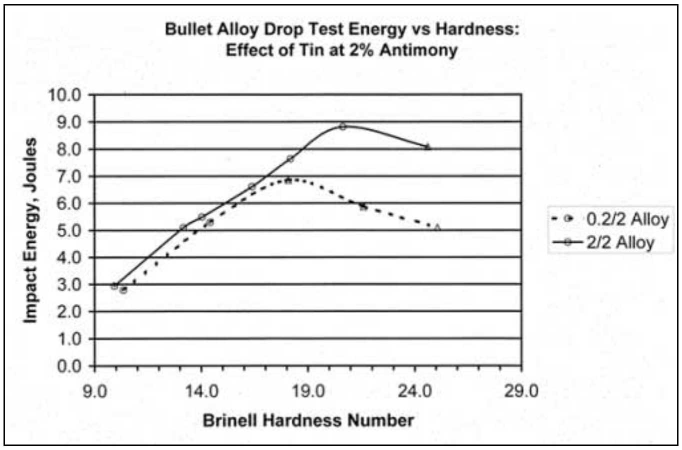

Chart 3

Up to 17 BHN there was little difference in the toughness of the two alloys. Above 17 BHN the pseudo-binary alloy was both tougher and more ductile, reaching its toughness peak of 9 Joules at about 21 BHN - slightly higher than the low-tin alloy's 19 BHN.

The second comparison was between 0.9/4 and 4/4 alloys. Results are shown on chart #4.

Once again the pseudo-binary alloy's peak toughness was greater at 9.6 Joules, and was reached at a higher hardness (23 BHN) – the peak hardness achievable for this alloy. There were insufficient data points to determine whether there was a difference in ductility between the low-tin and pseudo-binary alloys.

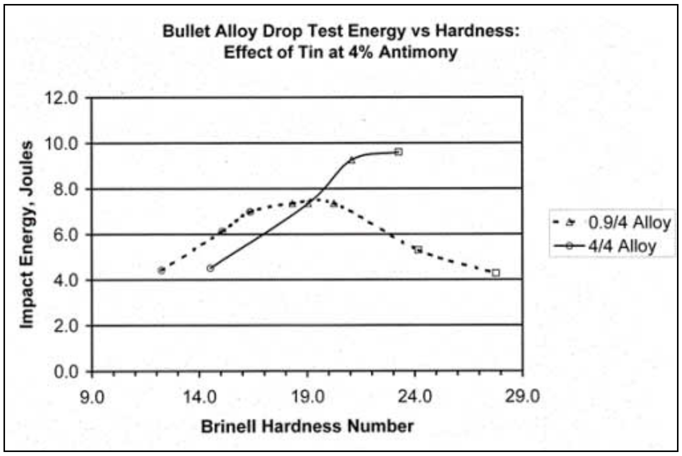

Chart 4

The third comparison was between 2/6 and 6/6 alloys. Results are shown on this chart.

As in both previous instances, the pseudo-binary alloy reached greater peak toughness (8 Joules) than the low-tin alloy but this time did so at only slightly higher hardness (20 BHN). As with the 4% antimony alloys, the pseudo-binary alloy's peak hardness was lower. The pseudo-binary alloy was the more ductile of the two.

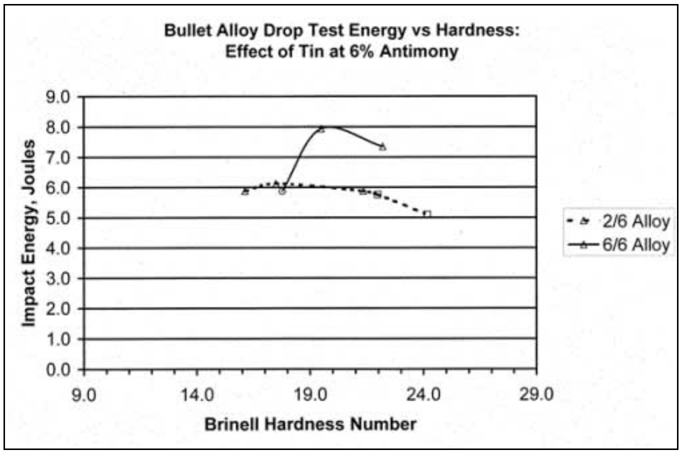

Chart 5

Six main observations can be made from these results. First, appropriate heat treatment enhanced the toughness of all alloys tested except 2/13, which even when air-cooled was at the 19 BHN optimum hardness for maximizing toughness. (The toughness enhancement from heat treating the next-highest-antimony low-tin alloy, 2/6, was very small.) Second, an optimum antimony content for maximizing peak toughness seemed to exist at somewhere around 4% antimony for both low-tin and pseudo-binary alloys. Third, every pseudo-binary alloy tested demonstrated substantially (26-29%) greater peak toughness than a low-tin alloy with the same antimony content. Fourth, the pseudo-binary alloys may have been more ductile than the low-tin alloys. Fifth, increasing the antimony content may have decreased the ductility of the alloys. Sixth, each alloy's ductility may have been decreased by heat treatment. More data would be required to confirm the last three of these points.

If the fifth and sixth observations are valid, greater hardness, whether it is attained by antimony content or heat-treatment, comes at the price of reduced ductility. However the data suggest that ductility can be increased by increasing the tin content, up to the point where tin and antimony contents are equal.

This report makes use of both theoretical and empirical information from F. D. Weaver, "Type Metal Alloys", Journal of the Institute of Metals Vol. LVI No. 1, 1935, pages 209-240.

- Geoff Chamberlain

**American Heritage Dictionary*
Joule (Pronunciation - jōōl, joul)
1. The International System unit of electrical, mechanical, and thermal energy.
2. a. A unit of electrical energy equal to the work done when a current of one ampere is passed through a resistance of one ohm for one second.
b. A unit of energy equal to the work done when a force of one newton acts through a distance of one meter.

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