UN/SCETDG/42/INF.28

**Committee of Experts on the Transport of Dangerous Goods and on the Globally Harmonized System of Classification and Labelling of Chemicals**

**Sub-Committee of Experts on the Transport of Dangerous Goods** **22 November 2012**

**Forty-second session**
Geneva, 3 – 11 December 2012
Item 2 (a) of the provisional agenda
**Recommendations made by the Sub-Committee on its thirty-ninth, fortieth and forty-first sessions and pending issues**
**Explosives and related matters**

# Comments on the similarity of results of the HSL flash composition test and the US flash composition test

**Transmitted by the expert from the United States of America**

## Introduction

1. At the forty-first session the Sub-Committee agreed to amend Note 2 of paragraph 2.1.3.5.5 in the default system for classification of fireworks in the Model Regulations and to add a new US Flash Composition Test to appendix 7 of the manual (see ST/SG/AC.10/C.3/82, para. 20-21 and STG/SG/AC.10/C.3/82/Add.1 (annexes I and II)). Recently, however, the expert from the Netherlands has submitted ST/SG/AC.10/C.3/2012/78 which expressed his continued reservations about the comparability of the results between the two test methods. In his analysis of all the 43 samples for which there were directly comparable results, it was observed that only 24 (56%) of the samples gave agreement between the two methods. Even with the new criterion of 6 ms in the HSL test, it was observed that the HSL test was still stricter in 17 cases. The conclusion of his analysis was that the low agreement was probably because the two tests address different explosive properties, i.e., the HSL test measures both deflagration and detonation phenomenon whereas the US Test measures detonation phenomenon only. The expert from the Netherlands therefore proposed a postponement of the adoption of US Flash Composition Test to the next biennium to generate additional comparable data and expand the criterion of the US Test to consider deflagration as well as detonation characteristics.

2. The additional information provided by the expert from the Netherlands is appreciated and the reservations he has raised are understood. Based on new comparative data, consistency of results between the two methods could potentially be improved. The US remains committed to implementing a more accurate, reproducible, and practical flash composition test. The US believes, however, that there was sufficient review and discussion over the previous several biennia to validate the alternative test finalized and adopted at the Sub-Committee's previous session. Implementation of the two methods should result in additional data that can be considered for enhancements to one or both methods in the future.

## Considerations Based on New Comparative Testing

3. It was stated by the expert from the Netherlands paper that the importance of identifying flash compositions for default classification is to classify fireworks with

potential mass explosion hazards as 1.1G and that mass explosion hazards do not only cover detonations but also (violent) deflagrations. Solid compositions containing both oxidizer and fuel elements deflagrate at various rates of speed depending on the uniformity and intimacy of the mixing. There is a spectrum of deflagration reaction rates ranging from meters per minute to Kilometers per second. The zone where deflagration rates become more violent and ultimately transition into detonations is quite broad and measures of that transition are subject to interpretation.

4. Fundamentally, the US does not disagree with the premise that the term "mass explosion" could encompass flash compositions which are capable of producing high and low-order detonations (also known as violent deflagrations). The effects of a wide range of pyrotechnic substances when confined in a steel sleeve and directed upon a mild steel witness coupon of nominally 1 millimetre thickness reflect varying degrees of damage, all the way from mild denting to, a tear or piercing of the plate. All types of damage were observed in the early US experimental trials, but it is believed that a tear or a puncture of the plate constitutes a pass/fail point that is both adequate and reasonably reproducible. This places the more violent deflagrating substances in the category of flash compositions, consistent with their higher risk of inducing damage or loss in a mass explosion.

5. However, it is noted that test results provided by the expert from Japan in UN/SCETDG/41/INF.42 provide an opportunity for additional research to assess whether the indentation depth of the steel witness coupons in the US Test could also be reproducibly used to quantify differences in damage effects between pyrotechnic compositions.

6. In order to provide additional data relevant to the work conducted by the Netherlands, fresh samples were prepared for sixteen of the twenty-two original sample compositions presented in ST/SG/AC.10/C.3/2012/30 working paper which did not have outcomes in agreement. Additionally, HSL Test Results were obtained for sample compositions 23-27. Three new black powder sample compositions were also added to the matrix to bring the total number of directly comparable results between the two test methods to thirty (30). A listing of all thirty compositions is shown in Table I.

## Assessment of Prior HSL Flash Composition Test Results Performed in the US

7. Considerable difficulties were previously encountered by the US to achieve consistent HSL Test results. This was discussed in ST/SG/AC.10/C.3/2012/30. Altogether four test fixtures were machined from the original engineering drawings provided in Appendix 7 of the Manual. Frequent breakdowns were experienced with the fixtures, often arising from the post-test igniter lead wire extraction from the set-screw arrangement in the reference drawing. For the most recent work, diagnostic tests were conducted on the original design fixtures by pressuring them with nitrogen gas to 300 psig. The fixtures gave variably medium to high leak-rates through the igniter set-screw holes. This inconsistent gas leak-rate was concluded to be the cause of discrepancies the earlier US-performed HSL test results. To remedy this problem, the HSL test fixture was slightly modified so that the igniter wire leads were not tightened with set screws that came through the fixture cross-threads, but up from the base of the test fixture with tightening screws as shown in Figure 1. In addition, the igniter wire lead holes were packed with silicone gel prior to each test. In this manner, the HSL fixture gas leakage fluctuations were minimized. More consistent results were then obtained for the HSL Test as shown in Table II. The earlier test results are contrasted with more recent data which showed considerable improvement in reproducibility.

## Assessment of the Prior US Flash Composition Test Results Performed in the US

8. When US flash composition test data from numerous other countries was compared with test results performed in the US, a better agreement with the HSL Test was observed from non US data. This led to a verification of the thickness of the witness plate coupons used to conduct all the previous US Tests. It was discovered that the mild steel witness plate material originally believed to have a nominal thickness of 1.0 +/- 0.05 mm. was actually 1.214 mm in thickness (18 Gage), or 21 per cent thicker than expected. Once this error was found, the prior data discrepancies between US and non-US test results became understandable. The witness plate thickness could obviously influence the yield points of the steel witness coupons, and would also affect any quantitative measurement of the indentation depths.

9. Rather than waiting for new witness plate coupons of the 1.0 mm thickness, it was decided to re-run the sample compositions using the 1.214 mm (18 gage) steel witness coupons and also run a select number of the those sample compositions with 0.912 mm (20 Gage) steel witness coupons to develop a correlation curve between the two thickness and then calculate a correction factor for converting the 1.214 mm indentation depth data back to the nominal 1.0 mm (if the plate wasn't pierced in any way). The linear correlation graph is shown in Figure 2.

10. Table III displays a summary of the all the US flash composition tests conducted on all thirty sample compositions to date and includes all prior data presented in ST/SG/AC.10/C.3/2012/30 against all the new and re-tested sample compositions. Only one sample composition (No. 3) was found to switch from (-) to (+) upon extensive re-testing (6 trials) based on plate piercing observations. Many sample compositions which were previously reported as not being flash compositions were found to have moderate to severe witness plate indentations and these are also documented in Table 3.

11. In this current study, for the plates that were not pierced, the indentation depths were measured by a different method than reported by the expert from Japan. A standard table micrometre gauge was fitted with an extended probe for measuring the concavity of the witness plate by difference from a "zero" height which was taken to be the height of the witness plate itself plus the height of its supporting ring, as shown in the top left photograph in Figure 3. The depth of all three trials (in millimetres) for each sample composition witness plate was measured separately (as shown in the various example photographs in Figure 3) then averaged. A correction factor of 1.52 was applied to calculate what the average indentation depth of the 1.214 mm (18 Gage) witness plates would be if they were actually 1.0 mm thick.

12. Piercing or tearing of the witness plates began to appear when the "corrected" 1.0 mm witness plate indentation depths reached 28-35 mm. When corrected indentation depths exceeded 35-40 mm, they were frequently accompanied by partial tearing or piercing of the witness plates at or near the corner folds. There seemed a natural transition from the data collected by the US in the vicinity of 11 to 14 mm, where the energetic release from deflagrations of the sample compositions began deforming the witness plates sufficiently to produce a "folding" at the corners, typically a precursor to actual piercing or tearing of the steel witness plates.

## Indentation Depth vs. Indentation Volume?

13. During the collection of this new data, a question arose as to whether it might be better to measure the indentation volumes in addition to indentation depths. There are

several ways of estimating displacement volumes of the indented witness plate. If it can be assumed that the indentation shape is approximately a spherical dish, the volume can be calculated from the depth of the indentation ("d") and the inner radius of supporting ring ("a" = 4.675 cm) according to the formula:

$$V_{dish} = \frac{\pi d}{6} [3a^2 + d^2]$$

14. The calculated volume of the spherical dish is proportional to the cube of the indentation depth. However, the problem with calculating the volume is that the indentations are not always spherical, particularly if the sample composition tube is not exactly centered on the witness plate and/or the witness plate is not exactly centered on the support ring. Perhaps a simpler method of measuring volume is simply filling the indentation to the water or sand up to the upper rim of the formed crater and then pouring the contained water or sand into a graduated cylinder. This would capture the aberrations in the spherical dish produced by minor mis-alignments.

# Conclusions

15. This new data shows that there is a good correlation between the energetic release of a pyrotechnic composition and the indentation depth on the mild steel witness plate. The correlation could also hold for indentation volume, whether calculated or experimentally measured by water or sand displacement, although additional data is needed to establish this beyond a reasonable doubt.

16. In those cases where the mild steel witness plate is not thoroughly punctured through, i.e., a catastrophic failure, quantitative measurements of indentation depth (or volumes) are perhaps a truer measure of energetic release in a pyrotechnic composition than minor "cracks" or small "tears" in the plate that may be produced. A metallurgical expert who examined this data has advised that small cracks or tears tend to be random and could be more related to the relative non-uniformity in the thickness or composition of the steel witness plate than the materials being tested.

17. A new assessment of the comparability of the two flash composition tests for thirty sample compositions is shown in in Table IV. New test results were used in all cases where there was prior disagreement. Using these new test results, there were only five disagreements in outcomes between the US and HSL Flash Composition Tests out of thirty sample compositions with the additional corrected indentation depth criterion of 14 mm or greater representing a (+) for the US Test. Thus, there can be at least 83 per cent comparability between the two flash composition test methods.

18. The input of other experts is now sought to review this new information and propose either further experimental work that could be done to improve the US Flash Composition Method or a final revision in the text of the test method or criteria if the experimental data is sufficient.

**Table I – A Listing of All Pyrotechnic Compositions Tested in both the HSL and the US Flash Compositions Tests in this Comparison**

| Sample Number | Sample Pyrotechnic Composition Descriptions |
|---|---|
| 1 | Goex “Black powder” -- 5FA “Unglazed” (made in USA) |
| 2 | 35 wt.% Potassium Nitrate (100% < 37 µ)/ 31% wt. Potassium Perchlorate (100% < 37 µ) /13.5% wt. % Potassium Benzoate (fine powder)/ 10 wt.% Sulfur (fine powder)/10.5 wt.% Lampblack (“nano” material). |
| 3 | 70 wt. % Potassium Perchlorate (100% < 37 µ) / 30 wt. % “Semi-coarse” Magnesium powder -- (297µ<25%>149µ; 148µ<58%>53µ; 52µ< 5%>44µ; 12%<43µ) |
| 4 | 65 wt. % Potassium Perchlorate (100% < 44µ)/ 35 wt. % Magnesium (105µ 5%>74µ; 73µ <39%>44µ; 46%<43µ) |
| 5 | 65 wt. % Potassium Perchlorate (100% < 44µ)/ 35 wt. % “Ground” Magnesium (100% <43µ) |
| 6 | 70 wt. % Potassium Perchlorate (100% < 37 µ)/ 30 wt, % “Atomized” Aluminum powder (74µ<2.4%>53µ; 52µ<2.9%>44µ; 94.7%<44µ) |
| 7 | 65 wt. % Potassium Perchlorate (100% < 44µ)/ 35 wt. % “Flake” Aluminum “A” (105µ <72%>53µ; 52µ <17%>44µ; 11.5%<43µ) |
| 8 | 65 wt. % Potassium Perchlorate (100% < 44µ)/35% “Flake ” Aluminum “B” (74µ<39% >53µ; 52µ<22%>44µ; 40%<43µ) |
| 9 | 70 wt. % Potassium Perchlorate (100% < 37 µ)/ 30 wt. % “Ground” Magnalium powder -- (74µ<37%>53µ; 52µ<11%>44µ; 52%<44µ) |
| 10 | 68 wt.% Barium Nitrate (105µ < 10% > 74 µ; 73 µ<12%>44 µ; 43 µ< 24%>37 µ; 53%<37 µ)/23 wt. % “Dark Flake” Aluminum (100%< 73 µ)/9 wt. % Sulfur (fine powder) |
| 11 | 85 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/ 10 wt.% Sulfur (very fine ground flour)/ 5 wt. % powdered charcoal |
| 12 | 80 wt. % Potassium Perchlorate (97% < 74µ & 3% < 37µ)/10 wt.% Sulfur (very fine ground flour)/10 wt. % powdered charcoal |
| 13 | 75 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/10 wt.% Sulfur (very fine ground flour)/15 wt.% powdered charcoal |
| 14 | 70 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/10 wt.% Sulfur (very fine ground flour)/20 wt.% powdered charcoal |
| 15 | 65 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/10 wt.% Sulfur (very fine ground flour)/25 wt.% powdered charcoal |
| 16 | 60 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/10 wt.% Sulfur (very fine ground flour)/30 wt.% powdered charcoal |
| 17 | 52 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/17 wt.% Sulfur (very fine ground flour)/5 wt. % powdered charcoal/26 wt.% Antimony trisulfide |
| 18 | 50 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/30 wt.% Sulfur (very fine ground flour)/20 wt.% powdered charcoal |
| 19 | 70 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/20 wt.% Sulfur (very fine ground flour)/10 wt.% powdered charcoal |
| 20 | 60 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/30 wt.% Sulfur (very fine ground flour)/10 wt.% powdered charcoal |
| 21 | 60 wt.% Potassium Perchlorate (97% < 74µ & 30% < 37µ)/20 wt.% Sulfur (very fine ground flour)/20 wt.% powdered charcoal |
| 22 | 48 wt.% Potassium Perchlorate (100 < 37µ)/52 wt.% Iron Powder (100% <45µ and 94% < 37µ) |
| 23 | Eurenco CSB-4 single base porous smokeless flake powder (a.k.a. “Solo 1000” in the USA) |
| 24 | Alliantech Systems “Green Dot” double base coated smokeless flake powder (made in USA) |
| 25 | 70 wt.% Potassium Perchlorate(97% < 74µ & 30% < 37µ) /30 wt.% Potassium benzoate (fine powder) – a typical “whistle-making” composition |

| | |
|---|---|
| 26 | 40 wt.% Potassium Perchlorate(97% < 74µ & 30% < 37µ)/60 wt.% ground magnesium powder (100% <43µ) |
| 27 | 50 wt. % Potassium Perchlorate(97% < 74µ & 30% < 37µ)/27 wt. % antimony sulfide powder/23 wt. % "Atomized" aluminum powder (74µ<2.4%>53µ; 52µ<2.9%>44µ; 94.7%<44µ) |
| 28 | Wasag Chemie WANO 2FA "Black Powder" (made in Germany) |
| 29 | Goex 2FA medium grain "Black Powder" (made in USA) |
| 30 | Goex 1FA coarse grain "Black Powder" (made in USA) |

**Table II – All Testing Performed with the HSL Flash Composition Fixtures**

| Sample Number | February 2012 Test Results ("Original HSL Design") from ST-SG-AC.10 C3-2012-30e | | | September 2012 Test Results ("Re-engineered HSL Design") | | |
|---|---|---|---|---|---|---|
| | Rise Times, Δt's, ms. | Min. Δt, ms. | Flash Com-posit-ion? | Rise Times, Δt's, ms. | Min. Δt, ms | Flash Com-posit-ion? |
| 1 | 2.9, 1.9, 2.2 | 1.9 | Yes | 3.7, 3.0, 3.9 | 3.0 | Yes |
| 2 | 3.9, 1.0, 0.9 | 0.9 | Yes | 5.7, 2.9, 2.3 | 2.3 | Yes |
| 3 | 6.3, 4.9, 6.8 | 4.9 | Yes | 2.9, 2.3, 2.5 | 2.3 | Yes |
| 4 | 7.7, 1.0, 1.9 | 1.0 | Yes | No Re-test | -- | -- |
| 5 | 0.4, 0.7, 0.3 | 0.4 | Yes | No Re-test | -- | -- |
| 6 | 2.8, 50.8, 92 | 2.8 | Yes | No Re-test | -- | -- |
| 7 | 0.4, 0.4, 1.1 | 0.4 | Yes | No Re-test | -- | -- |
| 8 | 0.4, 0.5, 0.6 | 0.4 | Yes | No Re-test | -- | -- |
| 9 | 9.6, 9.6, 114 | 9.6 | No | 1.1, 1.0, 3.3 | 1.0 | Yes |
| 10 | 2.0, 1.8, 1.4 | 1.4 | Yes | 1.0, 1.0, 1.3 | 1.0 | Yes |
| 11 | 8.3., 8.4, 85 | 8.3 | No | 3.6, 3.0, 4.1 | 3.0 | Yes |
| 12 | 8.2, 80, 91 | 8.2 | No | 8.6, 4.6, 5.4 | 4.6 | Yes |
| 13 | 1.7, 8.2, 8.2 | 1.7 | Yes | 2.3, 2.3, 2.7 | 2.3 | Yes |
| 14 | 2.6, 42.8, 25.2 | 2.6 | Yes | 1.9, 2.0, 3.2 | 1.9 | Yes |
| 15 | 2.1, 34.0, 8.0 | 2.1 | Yes | 1.7, 1.8, 2.5 | 1.8 | Yes |
| 16 | 3.0, 11.2, 12.8 | 3.0 | Yes | 2.2, 2.0, 1.9 | 1.9 | Yes |
| 17 | 2.1, 8.4, 19.2 | 2.1 | Yes | 3.9, 2.8, 2.5 | 2.5 | Yes |
| 18 | 3.7, 34.8,13.6 | 3.7 | Yes | 2.2, 2.1, 1.8 | 1.8 | Yes |
| 19 | 2.3, 20.0, 25.0 | 2.3 | Yes | 1,8, 1.7, 1.7 | 1.7 | Yes |
| 20 | 4.3, 19.4, 19.6 | 4.3 | Yes | 2.1, 2.2, 1.8 | 1.8 | Yes |
| 21 | 2.2, 24.4, 6.8 | 2.2 | Yes | 3.2, 3.8, 1.8 | 1.8 | Yes |
| 22 | >8 | >8 | No | No Re-test | -- | -- |
| 23 | Not Tested | N/T | N/T | 3.3, 2.8, 3.0 | 2.8 | Yes |
| 24 | " | " | " | 4.0, 4.2, 3.1 | 3.1 | Yes |
| 25 | " | " | " | 0.7, 1.0, 0.8 | 0.7 | Yes |
| 26 | " | " | " | 1.8, 1.2, 1.2 | 1.2 | Yes |
| 27 | " | " | " | 0.9, 0.8, 0.6 | 0.6 | Yes |
| 28 | " | " | " | 4.4, 5.9, 5.8 | 4.4 | Yes |
| 29 | " | " | " | 3.6, 4.9, 5.5 | 3.6 | Yes |
| 30 | " | " | " | 7.5, 8.9, 7.4 | 7.4 | No* |

*Using the recently amended minimum rise time of 6 milliseconds.

**Table III – All Tests Performed Using the US Flash Composition Method**

| Sample Number | February 2012 Test Results from ST-SG-AC.10 C3-2012-30e | September 2012 Test Results Using Both Piercing and Ave Dent Depth as measured and Corrected to 1 mm nominal Thickness | | | | |
|---|---|---|---|---|---|---|
| | 18 Gage (1.214 mm) Witness Plates Plate Pierced = (+) Not Pierced = (-) | 18Gage (1.214mm) Dent Depth, mm | Ave. 18 Ga. Dent Depth, mm | 20 Gage (0.912mm) Dent Depth, mm | Ave. 20 Ga. Depth, mm. | Corrected*Dent Depth to 1 mm. Plate Thickness |
| 1 | (-), (-), (-) | 9.5, 7.9, 8.5 | 8.6 | 11.7, 13.0, 13.9 | 12.9 | 13.1 |
| 2 | (-),(-), (-) | 19.7, 22.5, 21.5 | 21.2 | Not Tested | | 32.2 |
| 3 | (+), (-),(-),(-), (-), (-), (-), (-),(-) | (+),(+), (+),(+), (+),(-) | 26.8 (one test) | (+),(+), (+) | 44.3 (one test) | N/A |
| 4 | (+), (+), (+) | Not Re-tested | | | | |
| 5 | (+), (+), (+) | Not Re-tested | | | | |
| 6 | (+), (+), (+) | Not Re-tested | | | | |
| 7 | (+), (+), (+) | Not Re-tested | | | | |
| 8 | (+), (+), (+) | Not Re-tested | | | | |
| 9 | (+), (+), (+), (+), (+), (+), (+), (+), (+) | Not Re-tested | | | | |
| 10 | (-), (-), (-) | (+), 31.5, (+) | 31.5 | Not Tested | | 47.9 |
| 11 | (-), (-), (-) | 5.1, 5.7, 4.1 | 5.0 | Not Tested | | 7.6 |
| 12 | (-), (-), (-) | 23.5, 21.6, 7.9 | 17.7 | Not Tested | | 26.9 |
| 13 | (-), (-), (-) | 43.1, 26.6, 23.8 | 31.2 | Not Tested | | 47.4 |
| 14 | (-), (-), (-) | 10.1, 9.4, 23.0 | 14.2 | Not Tested | | 21.5 |
| 15 | (-), (-), (-) | 11.3, 11.1, 14.3 | 12.2 | Not Tested | | 18.5 |
| 16 | (-), (-), (-) | 8.6, 9.2, 11.7 | 9.8 | Not Tested | | 14.9 |
| 17 | (-), (-), (-) | 11.7, 7.3, 14.4 | 11.1 | Not Tested | | 16.8 |
| 18 | (-), (-), (-) | 6.2, 7.1, 7.9 | 7.1 | Not Tested | | 10.8 |
| 19 | (-), (-), (-) | 18.6, 20.7, 22.3 | 20.5 | Not Tested | | 31.2 |
| 20 | (-), (-), (-) | 11.3, 10.1, 8.6 | 10.0 | Not Tested | | 15.2 |
| 21 | (-), (-), (-) | 15.7, 17.6, 8.9 | 14.1 | Not Tested | | 21.4 |
| 22 | (-), (-), (-) | Not Re-tested – no indentation shown originally | | | | |
| 23 | (-), (-), (-) | 28.5, 20.6, 22.6 | 23.9 | (+), (+), (+) | -- | -- |
| 24 | (-), (-), (-) | 8.3, 10.6, 10.0 | 9.6 | 19.8, 19.5, 21.1 | 20.1 | 14.6 |
| 25 | (+), (+), (+) | Not Re-tested | | | | |
| 26 | (+), (+), (+) | Not Re-tested | | | | |

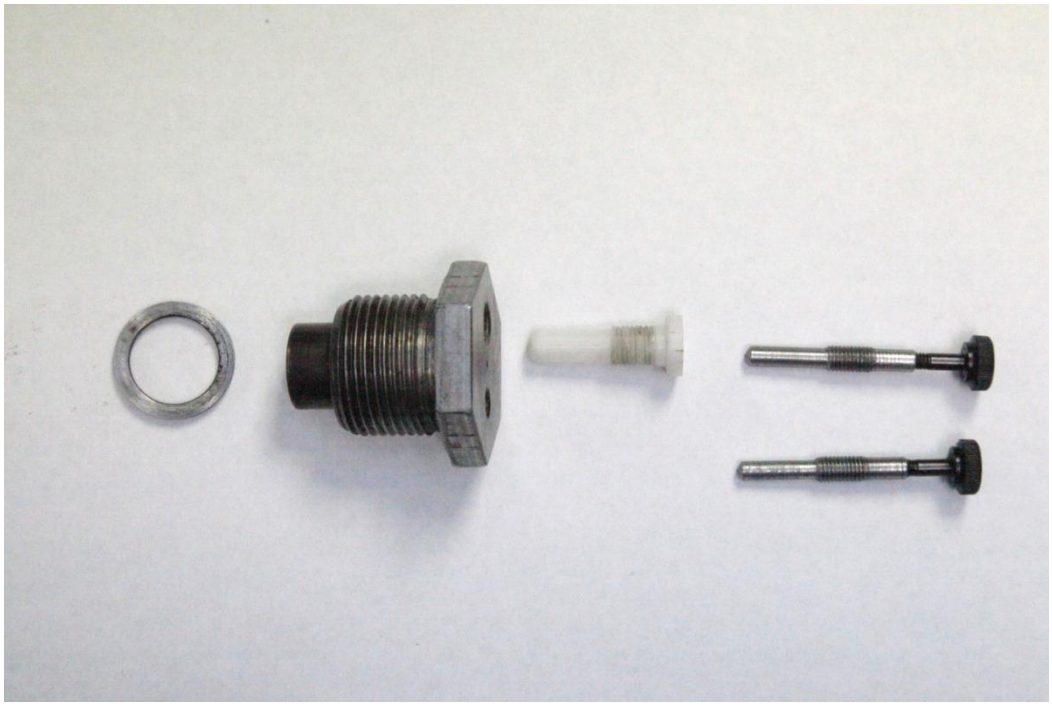
| | | | | | | |
|---|---|---|---|---|---|---|
| 27 | (+), (+), (+) | Not Re-tested | | | | |
| 28 | Not Previously Tested | 2.9, 2.8, 2.9 | 2.9 | 4.7, 3.9, 3.3 | 4.0 | 4.4 |
| 29 | Not Previously Tested | 4.2, 4.4, 4.6 | 4.4 | 5.4, 6.5, 5.4 | 5.8 | 6.7 |
| 30 | Not Previously Tested | 3.0, 3.5, 3.3 | 3.3 | Not Tested | | 5.0 |

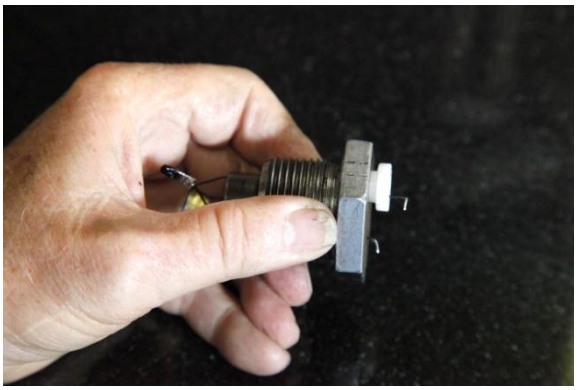
* Using a correction factor of 1.52.

**Table IV – A Final Comparison of HSL vs. US Flash Composition Methods**

| Sample Composition | HSL Flash Comp. Test Min. Δt, ms. *Tested Sept. 2012 | US Flash Composition Test *Tested September 2012 | | | Flash Composition by HSL? | Flash Composition by US? ** | A-gree ? ** |
|---|---|---|---|---|---|---|---|
| | | Uncorrected 18 Ga. Ave. Dent Depth, mm. | Corrected to 1.0 mm Ave. Dent Depth, mm. | Rank by Depth (Low to High) | | | |
| 1 | 3.0* | 8.6* | 13.1 | 7 | Yes | No | ***No*** |
| 2 | 2.3* | 21.2* | 32.2 | 17 | Yes | Yes | Yes |
| 3 | 2.3* | 5 of 6 Pierced* | 40.4 (one test) | 19 | Yes | Yes | Yes |
| 4 | 1.0 | Pierced | N/A | N/A | Yes | Yes | Yes |
| 5 | 0.4 | Pierced | N/A | N/A | Yes | Yes | Yes |
| 6 | 2.8 | Pierced | N/A | N/A | Yes | Yes | Yes |
| 7 | 0.4 | Pierced | N/A | N/A | Yes | Yes | Yes |
| 8 | 0.4 | Pierced | N/A | N/A | Yes | Yes | Yes |
| 9 | 1.0* | Pierced | N/A | N/A | Yes | Yes | Yes |
| 10 | 1.0* | 31.5* | 47.9 | 21 | Yes | Yes | Yes |
| 11 | 3.0* | 5.0* | 7.6 | 5 | Yes | No | ***No*** |
| 12 | 4.6* | 17.7* | 26.9 | 15 | Yes | Yes | Yes |
| 13 | 2.3* | 31.2* | 47.4 | 20 | Yes | Yes | Yes |
| 14 | 1.9* | 14.2* | 21.5 | 14 | Yes | Yes | Yes |
| 15 | 1.8* | 12.2* | 18.5 | 12 | Yes | Yes | Yes |
| 16 | 1.9* | 9.8* | 14.9 | 9 | Yes | Yes | Yes |
| 17 | 2.5* | 11.1* | 16.8 | 11 | Yes | Yes | Yes |
| 18 | 1.8* | 7.1* | 10.8 | 6 | Yes | No | ***No*** |
| 19 | 1.7* | 20.5* | 31.2 | 16 | Yes | Yes | Yes |
| 20 | 1.8* | 10.0* | 15.2 | 10 | Yes | Yes | Yes |
| 21 | 1.8* | 14.1* | 21.4 | 13 | Yes | Yes | Yes |
| 22 | >8 | 0 | 0 | 1 | No | No | Yes |
| 23 | 2.8* | 23.9* | 36.3 | 18 | Yes | Yes | Yes |
| 24 | 3.1* | 9.6* | 14.6 | 8 | Yes | Yes | Yes |
| 25 | 0.7* | Pierced* | N/A | N/A | Yes | Yes | Yes |
| 26 | 1.2* | Pierced* | N/A | N/A | Yes | Yes | Yes |
| 27 | 0.6* | Pierced* | N/A | N/A | Yes | Yes | Yes |
| 28 | 4.4* | 3.9* | 4.4 | 2 | Yes | No | ***No*** |
| 29 | 3.6* | 4.4* | 6.7 | 4 | Yes | No | ***No*** |
| 30 | 7.4* | 3.3* | 5.0 | 3 | No | No | Yes |
| ** US Test criteria includes both piercing or corrected indentation depths ≥ 14.0 mm | | | | | | | |

**Figure 1 – Illustrations of Revisions of the HSL Test Fixture to Minimize Gas Leakage Through the Igniter Wire Connection Ports**





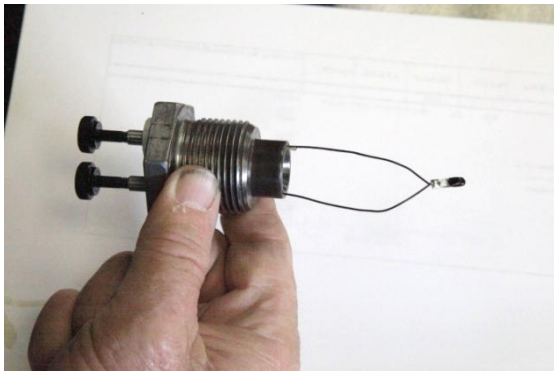
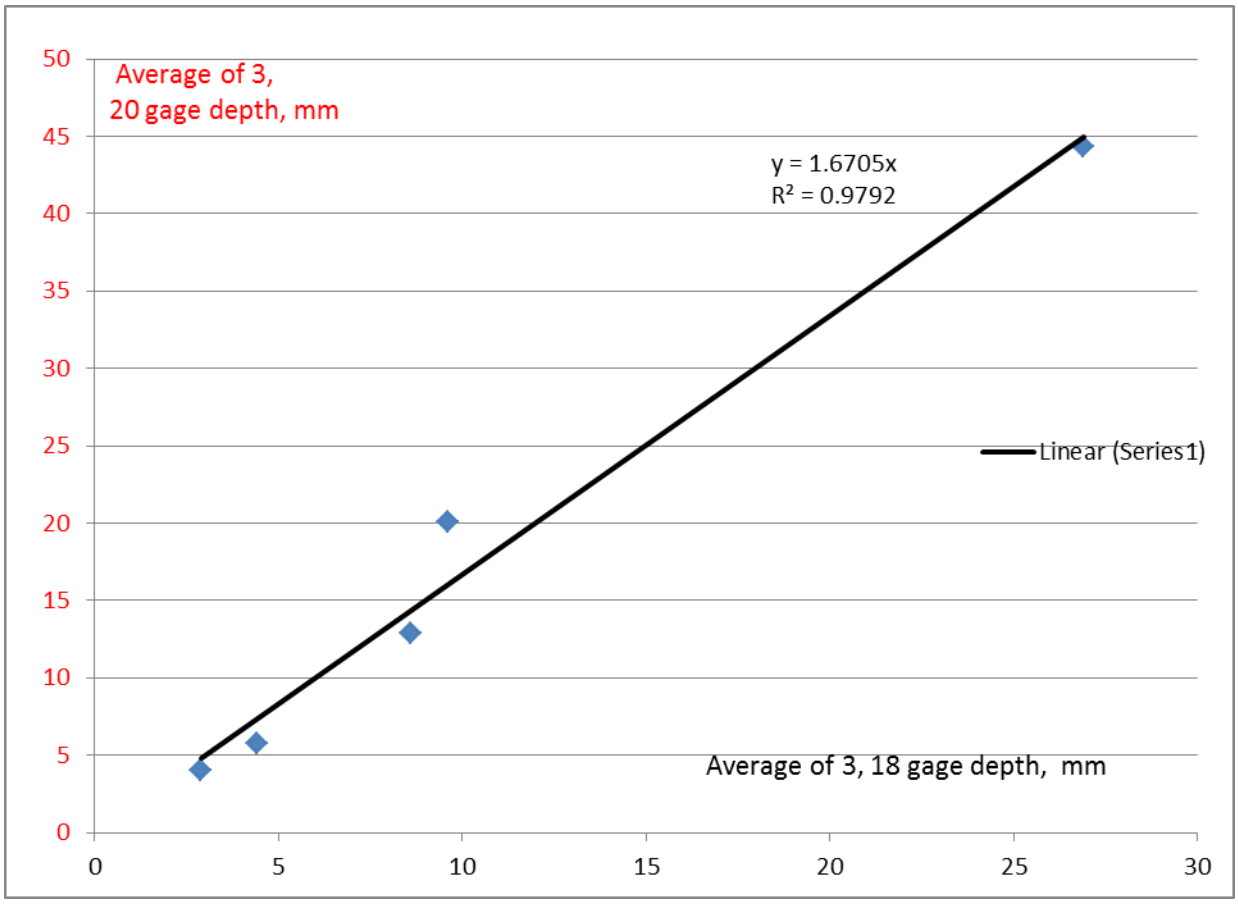


**Figure 2 – Correlation Curve of Indentation Depths for 1.214 mm (18 Gage) vs. 0.912 mm (20 Gage) Cold Rolled Mild Steel Witness Plates**

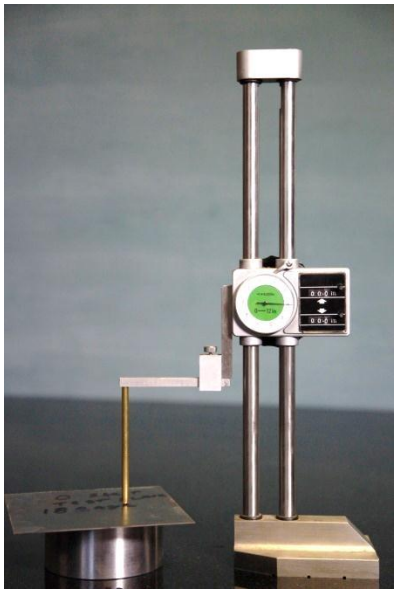



To estimate the average indentation depth at 1.0 mm nominal , the slope of the line for 1.214 mm (18 Gage) vs. 0.912 mm (20 Gage) was multiplied by $\frac{0.912}{1.000}$

Correction Factor ( to convert from 1.214mm to 1.00 mm) = 1.67 x 0.912

= **1.52**

**Figure 3 – Illustration of the US Test Dent Depth Measuring Technique**



"Zeroing the Gauge"