S. Tribology (ASP 230[i])

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Contractor: U.S. Automotive Materials Partnership
Contract No.: DE-FC05-02OR22910

Objectives

- Conduct stamping simulation tests to study the effects of tribological conditions on the stamping performance of advanced high strength steels (AHSS). Stamping performance in this project is defined as minimizing die wear and identifying the optimum die materials and lubricants for AHSS.
- Include these ultimate benefits:
  - Improve test procedure to simulate die wear.
  - Define a model for prediction of die wear.
  - Optimize lubricant/die combinations for AHSS.
  - Maintain common lubricants among automotive companies and steel suppliers.

Approach

- Examine wear rates of different die materials, die-surface treatments and lubricants with advanced high-strength steels.
- Comparison of wear rates with different lubricants and die materials.
- Evaluation of methods of improving die life.
- Optimized lubricants/die combinations for advanced high-strength steel.
- Project consisting of L16 (DoE) two material grades, two thickness, two sheet coatings, two bead radiis, two lubricants and two bead coatings.

Accomplishments

- Completed Phase 1 report "Enhanced Stamping Performance of High Strength Steels with Tribology."
- Completed Phase 2 report "Effect of Stroke Length and Penetration on Die Wear."
- Obtained steel coils of galvanized & galvannealed HSLA340 and DP600 supplied by partner companies.
- The material is used in the wear tests for Phase 3.
- Collected data for the eight test conditions.
- Completed Phase 3 report "Enhanced Stamping Performance of High Strength Steels with Tribology – Report on Phase 3 Testing."

Future Direction

- Develop wear rate model to predict die life.
- Gather wear test data to substantiate model.
- Correlate model with production data as AHSSs come into production.

Progress Report

October 1, 2005 to September 30, 2006:

A project was initiated to improve the understanding of the effects of lubricants on die wear and part dimensional variation (springback due to interfacial friction) associated with stamping of high-strength steels. Die material will also be studied. Advanced high-strength steels (AHSS) may require different lubricant and/or die material to minimize die wear, achieve consistent friction, and reduce part variation.

Improving the Life of High-Strength Steel Stamping Dies:

Executive summary:

The scope and objectives of this study grew out of previous work of the Auto/Steel Partnership Tribology Team. Findings in Phase 1 (2002) and Phase 2 (2003) of this project highlighted potential issues with the stamping of AHSS. Drawbead tests revealed much higher restraining forces and evaluated temperatures with DP600 over AKDQ and HSLA steels. How would the higher contact stress and elevated part temperature associated with AHSS effect die life? How would part geometry be affected? What process changes such as lubricants and die treatments can be used to increase die life and improve process capability? Phase 3 (2005) investigated the differences between AKDQ, HSLA and DP600 steels with respect to die temperature and restraining force on die wear test. Phase 3 results showed that factors other than sheet strength were important in determining heat transfer to the dies. Also, restraining force decreases with the number of parts produced.

The Die Wear Test was developed by TribSys Inc. to measure die wear at production volumes and rates. Earlier studies had been limited to 12,000 parts. The Phase 4 plan was to study wear with AHSS in the forming of 48,000 parts for 16 different test conditions (a total of 768,000 parts).

The tests were run over a period of three months at production rates averaging 15,000 per day. Data were collected and analyzed using software specifically designed for this experiment.

Statistical analysis of the data shows that that restraining force or stress is most influenced by the sheet thickness and bead radius. Surprisingly, sheet coating was also found to be a significant factor. Thinning strains measured on the collected samples throughout the test confirm these results. One significant result was the difference between HSLA and DP600 increases as sheet thickness increases.

Wear-volume measurements show both abrasive and adhesive wear. The type of wear was generally related to the type of bead coating. In general, adhesion was heaviest with the galvanized sheet while abrasion was heaviest with the galvanneal sheet. The effect of wear on restraining force and

thinning strain was not directly related to one type of wear but more on the nature of the worn surface.

The run-in period for each test was analyzed and revealed that the harder, more abrasive GA coating achieved a stable restraining force sooner than the softer GI coating. In addition, the CrN coating had a much shorter run-in period than the uncoated D2 for most conditions.

The final report along with conclusions is not yet completed.

Other Technical Papers:

Five (5) technical papers on the results of Phases 1, 2 & 3 are being written.

1. Characterizing Automotive Sheet Steel & Lubricants.
2. Temperature Effects with Film Lubricants in Stamping AHSS.
3. Comparison of Mill Applied Lubricants on AHSS using Draw Bead Simulator and Twist Compression Test.
4. Sensitivity of Zinc Coatings on Stampings.
5. Effects of Penetration and Stroke Length on DBW Patterns.

Trim Die Wear Study: A Trim Die Wear study was conducted on prestrained, advanced high-strength steels to evaluate wear rates with two materials AISI A2 and AISI S7 with the goal of comparing trim die suitability of these two die materials.

The use of advanced high strength steels (AHSS) and ultra high strength steels (UHSS) is steadily increasing in the automotive industry. There are anecdotal reports that these steels are causing trim dies to wear out prematurely [1]. Trimming processes are used to remove excess sheet metal from stamped parts and are a crucial factor for assembly and overall dimensional quality.

Tribological experiments are helpful in developing an understanding of the effects of the accelerated wear associated with the processing of AHSS. These experiments can determine the type of wear the tool steel will be subjected to such as face wear, flank wear, or edge wear (Figure 1[2]).

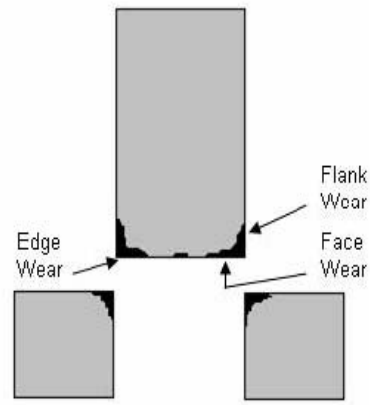


Figure 1. Types of punch/die wear.

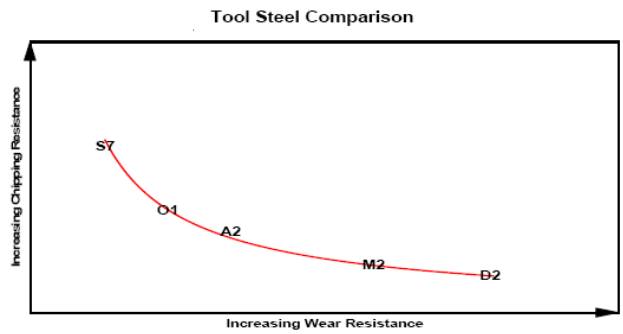


Figure 2. Tool steel comparison chart.

There are many variables in trimming that can affect die life. These variables, related to tool materials, lubricants, and sheet can be studied in controlled experiments to better understand their influence on the trimming process. [2].

In this study, we examined the effect of tool materials on trim die life. Two common trim die materials were chosen to represent current industrial practice for wear and chipping resistance (Figure 3). The intent of this study was to establish a die-wear baseline with pre-strained AHSS material, whereas previous studies have examined die life with unstrained (as received) material [3]. Testing the material in the pre-strained form should improve the accuracy and relevance of the study for the stamping industry.

Experimental Methodology

***Experimental Design**:* The study of trim die materials was run concurrently with a larger experiment where eight different sheet steels were

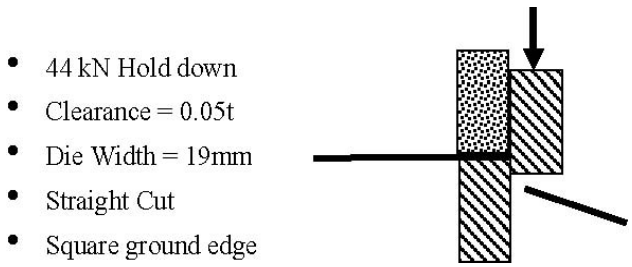


Figure 3. Setup.

tested in a coil-fed drawbead simulator. The trim dies were designed to be changeable half-way through the experiment without disrupting the drawbead simulator setup. The sheet steel tests were split up evenly, so that each of the two trim die sets saw the same material type and thickness. By the end of the test, the S7 and A2 trim dies had each made a total of 384,000 cuts.

***Die Materials**:* Two widely used tool steels, AISI A2 and AISI S7, were selected for this experiment [4]. These tool steels were machined and hardened to specification by a local heat treating company [5]. The trim dies were ground parallel to the trimming edge of the die; while this is not the optimal orientation for grinding dies (parallel to punch movement is recommended [6]), it is common practice and should represent a worst case scenario. The sharp right angle produced on the die edge by grinding was not beveled in any way prior to testing.

Sheet Materials: Two thicknesses (1.2 mm and 1.6 mm) of DP600 and 340XLF grade steel with galvanneal and galvanized zinc coatings were coil fed into the test apparatus. The 50 mm-wide strips were trimmed after being pre-strained in a drawbead simulator. Thickness strains of the pre-strained sheet ranged from 5.6% to 22.7%. Since the trim die study was run concurrently with the drawbead wear study, there was no attempt to hold the sheet material properties constant. The range of grades, coatings, thicknesses, and strains could be considered at an average to establish the severity of the test conditions for long-term wear effects (abrasive wear). The worst conditions (DP600, 1.6 mm and high strain) established the severity for short-term wear effects (stress cracking).

***Equipment Setup**:* The trim dies were installed to ensure the mating surfaces were clean and free of oil and debris. The trim die clearance was set to 5% of as received material thickness. This clearance was maintained for the two different sheet materials by adjusting the lower trim die shims. The effective clearance was roughly 7% of the strained materials. The upper trim die was fixed to a hydraulic cylinder, sliding within a confined guiding system. The guides had very tight tolerances that ensured the trimming blades had little or no play. The blades were a straight design with a zero-degree shearing angle; while this maximized cutting force, it made it easier to set the trim die clearance and once again was considered as the more severe condition. This upper moving assembly was regularly greased and cleaned of any debris that may inhibit trimming performance, and the hydraulic cylinder was sized to accommodate the high forces required to shear the strained AHSS.

The die wear tester ran at approximately 30 cycles per minute, where each cycle consisted of a clamp/cut. Material was then pulled through the die; the clamp was released and then returned to the starting point where the cycle was repeated (Figure 3). The only lubrication present was two varieties of mill-applied lubricants, standard rust preventative mill oil and the other, a mill-applied wax. It was felt the small amount of lubricant present would have a negligible effect on the trim die life, since there would be no cooling effect, and there were no EP additives present.

Trimmed material samples were collected throughout the test at 2-hour intervals, which is approximately 3600 cycles. Each sample was labeled with the appropriate test number, time and stroke count. These samples were used for analysis of trim quality. Once all tests were completed, the trim dies were removed, cleaned and set aside for analysis.

Results

Trim Die Condition: The trim dies were inspected for cracking, chipping or any other easily visible wear. Photos and microscopic images were taken of both the upper and lower trim dies. The time of the chipping was traced after testing was completed by examining the edge of the collected samples; thus, the occurrence of chipping is accurate within approximately 3600 cuts.

AISI S7: The S7 die produced the best trim quality and chipping resistance of the two tool steels. The S7 showed no signs of cracking or heavy chipping. The edges of both the upper and lower dies showed very light edge wear (rounding). The S7 die did show heavier signs of face and flank wear easily visible to the naked eye (Figure 4).

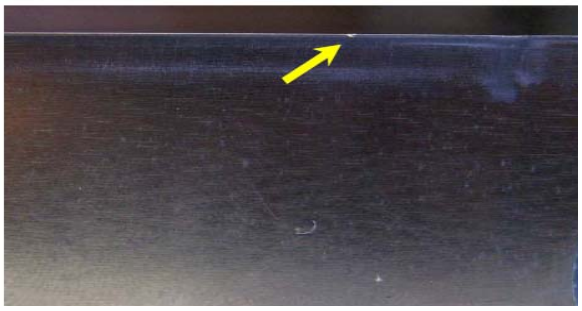


Figure 4. S7 lower trim die edge.

Examination of the sheet specimens trimmed with the S7 die showed that trimmed edge quality did not significantly deteriorate from the start to end of the test (Figure 5 and Appendix 2A). There was a slight increase in burr height associate with the rounding of the trim die edge. What appeared to be a small chip on the lower die (see arrow, Figure 4) proved to have been present at the start of testing (as revealed by close examination of the trimmed sheet specimens). It is thought that this small dent occurred during handling prior to the start of the test. The damage area (dent) did not appear to worsen during the 384,000 cuts nor did it seem to have affected trimming performance.

AISI A2: The A2 trim dies did not perform as well as the S7 dies. Sign of flank wear and face wear were minimal, but very heavy chipping occurred at different stages of the test. Approximately 35% of the cutting edge on the lower trim die had been chipped off (Figure 6), leading to a very poor trim quality of the test specimens by the end of the test. The upper portion of the cutter remained intact and showed minimal signs of wear. The differences in wear between the lower trim die and upper trim die can be attributed to reduced stress on the upper cutter (free-end side of the strip).

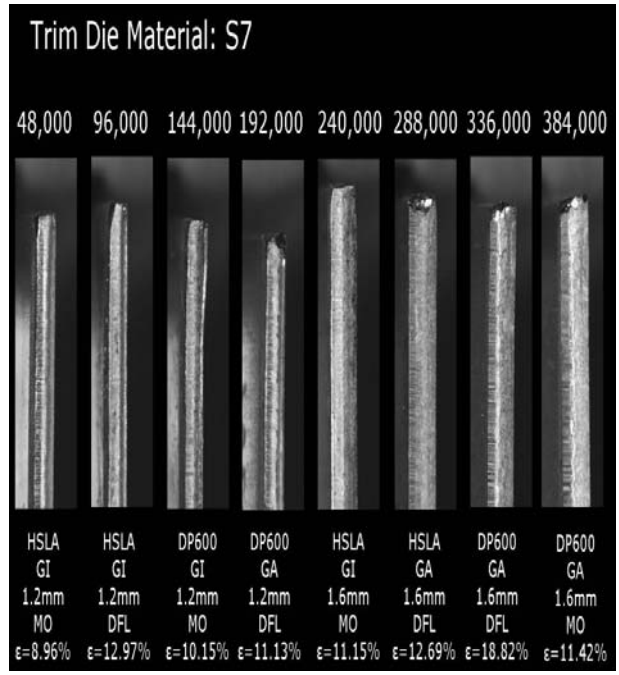


Figure 5. S7 trim specimen edge quality.

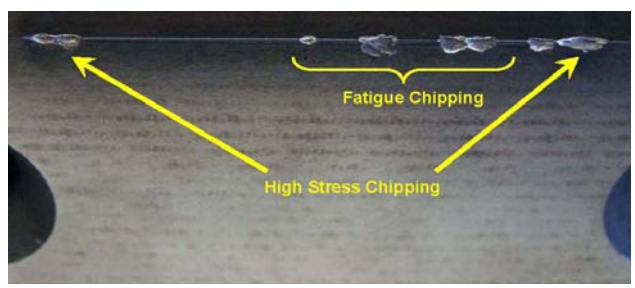


Figure 6. A2 lower trim die edge.

Study of the trim dies and trimmed sheet specimens show that there were two distinctly different types of chipping:

1. Early chipping at the point of contact of the sheet edge.
2. Late test chipping at the midpoint of contact.

The early chipping initiated at the contact with the edge of the sheet is thought to have been caused by the high local stresses (Figure 7). Sheet specimens reveal that this chipping occurred after only

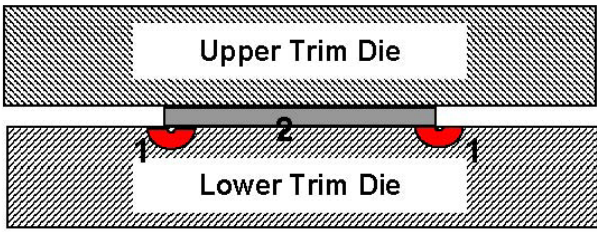


Figure 7. Stress concentration at edge of sheet.

132,760 cuts. The opposite side of die chipped after 235,250 cuts.

The chipping that occurred later in the test started at the midpoint of contact with the sheet was found after 354,900 cuts. It appeared to be unrelated to the earlier chipping at the strip edge. After the first chip was found, others formed rapidly within the final 30,000 cycles. It is likely that the cause of the second type of chipping was cyclic fatigue at moderate stress levels.

Sheet specimens: The chipping did not prevent the trimming of the material, but affected trimmed edge quality (Figure 8 and Appendix 2B). The samples were heavily burred at the corresponding chip location on the die, (Figure 9). The areas which were free of chips, maintained a very good trim quality. Due to the high hardness of the A2 material, the face wear and flank wear were minimal.

Discussion: The A2 and S7 tool steels are commonly used in the metal-forming industry. A2 is roughly 4 HRC higher than S7 in hardness [Appendix 1]; the greater hardness of A2 can be attributed to higher carbon content and the increase in carbides formed. This higher concentration of carbides is the result of

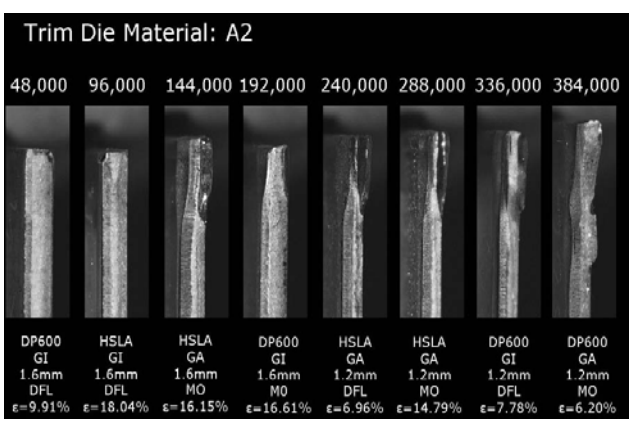


Figure 8. A2 trim specimen edge quality.

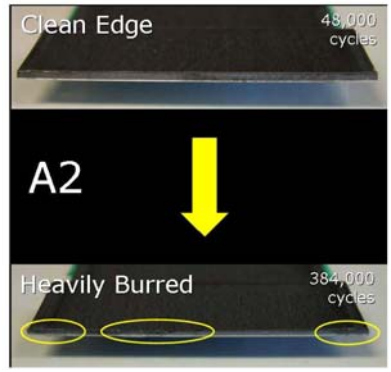


Figure 9. Specimen edge quality on A2.

higher carbon content; greater than 0.5% by weight, and carbide alloying elements such as vanadium, molybdenum and chromium [4]. These stable carbides produce better abrasive wear resistance properties. S7 sacrifices abrasive wear resistance for improved toughness.

Toughness provides resistance to cracking and chipping caused by high local stress (Figure 10). The lower hardness in S7 is responsible for the increased edge; flank and face wear (Figure 11).

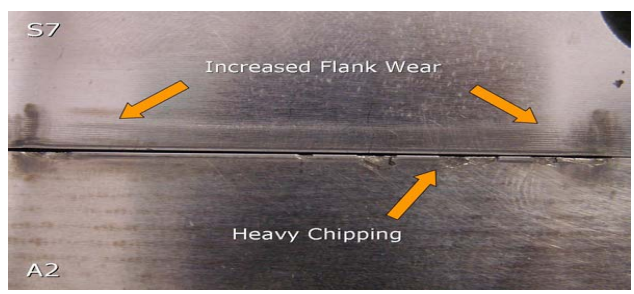


Figure 10. S7 vs. A2 Trim Die Wear.

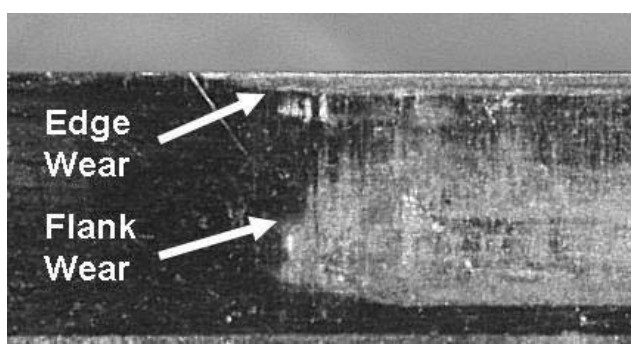


Figure 11. S7 trim die wear.

The wear rates seen in the test simulate what would be seen in an industrial application. The material was pre-strained from 5% up to 20%, resulting in a much harder material to trim than unstrained, as-received sheet.

The sheet edge condition that caused the chipping of the A2 trim die cannot be considered typical of trim dies since trim dies may not encounter sheet edges; however, shearing across a sheet edge is common in blanking dies and is similar to conditions found in trim dies for stampings using tailor welded blanks where a thick sheet is joined to a thinner sheet.

Conclusion

These trim die tests were conducted as part of a larger study and as a consequence each trim die processed a variety of material types, thicknesses and coatings. Each trim die made 384,000 cuts at a rate of approximately 30 parts per minute in prestrained AHSS sheet. It is felt that these conditions are representative of industrial practice.

The comparison of AISI A2 versus AISI S7 tools steels for trimming advanced high-strength steels revealed in the superior performance of the S7 tool steel. Even though the S7 showed a slightly higher abrasive wear rate, it produced excellent trim quality on all material types and thicknesses. No signs of chipping occurred in the S7, whereas the A2 suffered extensively from chipping, even though it had better abrasive wear resistance. Under the conditions that were tested, it can be concluded from this study that S7 would be a better choice for AHSS trim dies particularly applications where a sheet edge causes high local stresses. Further testing involving varying the set clearances of the trim dies for the AHSS may reveal different performance aspects for the two tool steels.

References

A/SP Tribology team and Die Materials Subcommittee discussions.

Schey, J. Tribology of Metalworking, ASM Publication 1983

Skare, T, Krantz, F. Wear and frictional behaviour of high strength steel in stamping monitored by acoustic emission technique, Wear 255 (2003) 1471-1479, Elsevier Science B.V.

Crucible Tool Steel and Specialty Alloy Information.

Northern Heat Treat Ltd.

Dayton Progress Corporation, private discussions.

Appendix 1 (From Crucible Steel Specifications sheets)

Component	**Weight Percent**
Carbon, C	1
Chromium, Cr	5.25
Iron, Fe	91.55
Manganese, Mn	0.85
Molybdenum, Mo	1.1
Vanadium, V	0.25
Mechanical Properties	
Hardness, Rockwell C	62

Table I.1 – Crucible AISI A2 chemical composition

Heat Treating Cycle: Austenitizing Temperature/Time /Draw: 1750˚F/ 120 min/300˚F min [5]

Weight Component Percent Carbon, C 0.55 Chromium, Cr 3.25 Iron, Fe 93.5 Manganese, Mn 0.7 Molybdenum, Mo 1.4 Silicon, Si 0.35 Vanadium, V 0.25

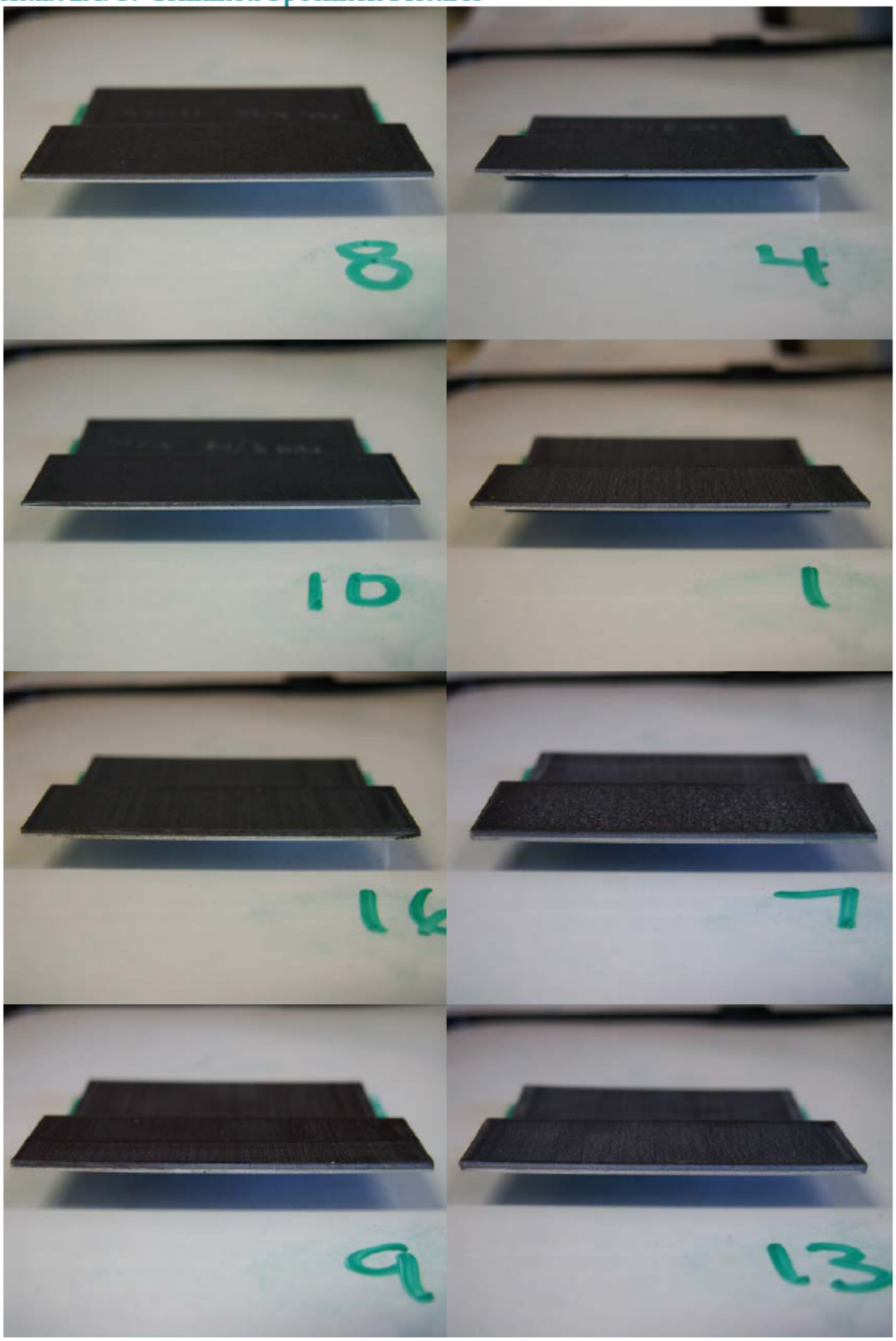
Mechanical Properties

Hardness, Rockwell C 58

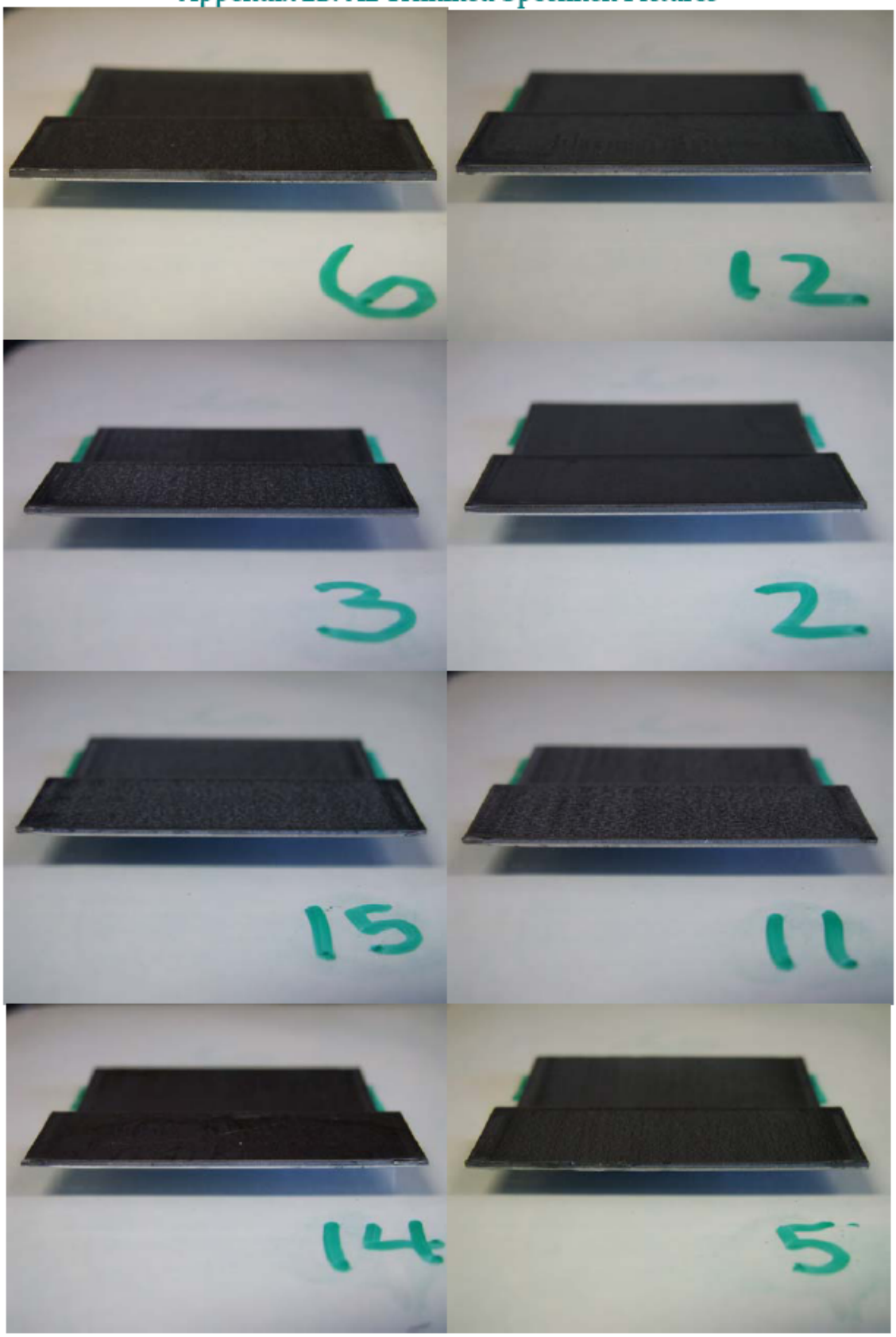
Table I.2 – Crucible AISI S7 chemical composition

Heat Treating Cycle: Austenitizing Temperature/Time/Draw: 1725˚F/ 120 min/ 300˚F min [5]

Appendix 2A: S7 Trimmed Specimen Pictures



Appendix 2B: A2 Trimmed Specimen Pictures



[i] Denotes project 230 of the Auto/Steel Partnership (A/SP), the automotive-focus arm of the American Iron and Steel Institute. See www.a-sp.org. The A/SP co-funds projects with DOE through a Cooperative Agreement between DOE and the United Sates Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the "Big Three" traditionally USA-based automakers to conduct joint pre-competitive research and development. See www.uscar.org.