A fractured input shaft used in NASCAR racing was received for analysis to investigate the cause of failure. Results indicate the shaft fractured due to fatigue progression from an intergranular stress crack, initiated at a dot peen identification marking on the shaft. The dot peened engraving creates a high stress concentration in the hard surface (54 Rockwell C – HRC) of the part. A shallow zone of intergranular fracture was noted, which initiated at the bottom of the dot peened lettering on the shaft. Two events of fatigue progression were observed covering approximately 33% of the fracture surface, prior to final torsional overload failure of the component. Intergranular cracking at the initiation site indicates a brittle surface condition and may be an indicator of excessive residual stress in the surface of the shaft.

Metallographic analysis of the fracture revealed secondary, incipient intergranular cracking at the bottom of adjacent dot peen marked lettering. No unusual conditions were observed in the martensitic microstructure of the shaft.
Spectrographic chemical analysis of the input shaft indicates the component was manufactured from 300M, ultra-high strength, alloy steel. No unusual conditions were observed in the elemental composition.

The high hardness of the 300M shaft makes the component highly notch sensitive with very little ductility. The dot peen marked lettering provided a notch effect and site for fracture initiation.

Chemical analysis and hardness testing was performed on two additional input shafts. The input shaft from the No. XX car, with the same date code as the fractured component, was manufactured from SAE 300M ultra-high strength steel. Hardness testing indicated the 300M material exhibited an average core hardness value of 55 HRC.

Chemical analysis and hardness testing of the input shaft from the No. XX car, with a different date code, was manufactured from SAE 9310 high strength carburizing steel. The component is likely carburized in the splined regions. Hardness testing at the mid-radius of the shaft cross-section indicated an average core hardness of 38 HRC.

ANALYSIS:

A fractured XXXXXX 300M ultra-high strength steel transmission input shaft was received for analysis. An overview of the fractured input shaft (top) and two comparison shafts (No. XX and No. XX cars from XXXXXXX NASCAR race) are presented in Figure 1. The No. XX Car input shaft fractured following approximately 254 miles of racing. Close-up views of the fractured input shaft appear in Figures 2 and 3. The fracture crosses the "0" in the date stamp on the part (arrows), which was created using a "dot peening" process.

Figure 4 provides a low angle view of the mating fracture surfaces of the input shaft. The arrow points to the fracture origin in reference to the dot peen marked date code. A slightly different angled view shows markings on the fracture surface in Figure 5, which indicate fatigue progression and initiation at the dot peened "0" on the shaft.

A close-up view normal to the fracture surface (Figure 6) reveals the fracture origin and two fatigue events that cover approximately 33% of the fracture surface, before final torsional twist off of the shaft. The highly oxidized portion of the fatigue zone indicates this portion was open and had arrested for some time before fracture propagation continued.

The fracture surface was examined at high magnification using a scanning electron microscope (SEM). A low magnification SEM view of the fracture surface in the area of initiation appears in Figure 7. Intergranular fracture, indicative of a high hardness, brittle condition is noted. This may also be an
indicator of very high residual stresses in the surface of the shaft. The fracture surface markings indicate two events transpired, prior to final overload failure.

The fracture origin is observed in the boxed region that is presented at increasing magnification in Figures 8, 9 and 10. The fracture origin is at the bottom of one of the dot peen marked letters. Brittle intergranular fracture is observed adjacent to the fracture origin.

Figures 11, 12 and 13 provide increasing magnification SEM views of the shaft OD surface at the fracture origin. Fracture initiated at the vertical line of the "0" in the date code engraving. A SEM, backscatter electron (BSE) image of the initiation site is presented in Figure 14. The BSE image is more sensitive to topographical variations. Secondary cracking in the bottom of the dot peen mark is noted.

A low magnification SEM/BSE image of an adjacent letter ("I") is detailed in Figure 15. The boxed region is presented at increasing magnification in Figures 16 and 17. Secondary, intergranular cracking is observed in the bottom of the dot peen letter.

A transverse cross-section was taken through the fracture origin and prepared for metallographic examination per ASTM E3-01. Etching with 2% Nital in accordance with ASTM E407-99 revealed the microstructure that was examined using an optical microscope in accordance with ASTM E883-02.

Figure 18 presents an optical microscopic image of the cross-section at the fracture origin. An impression in the surface at the fracture origin is the result of the dot peen marking. An additional impression is observed below the fracture origin. A high magnification optical view of the fracture origin appears in Figure 19. The fracture surface exhibits evidence of brittle intergranular fracture. No unusual conditions are observed in the martensitic microstructure.

A high magnification view of the adjacent dot peen letter indentation in the shaft surface in the cross-section is shown in Figure 20. A small, incipient, intergranular crack is observed at the bottom of the dot peen impression. An increased magnification, un-etched view of the crack is detailed in Figure 21.

Spectrographic analysis per ASTM E415-99a was conducted to determine the chemical composition of the fractured input shaft. The analysis identified the material as meeting the chemical composition of 300M, ultra-high strength, alloy steel. No unusual conditions were observed in the composition. Chemical composition results are provided in Table 1.

Rockwell hardness testing was performed at the mid-radius on a transverse cross-section through the shaft in accordance with ASTM E18-02. Four separate readings were taken at random locations on the cross-section for an average
hardness value of 54.5 HRC. Knoop 500 gram load microhardness testing (ASTM E384-99e1) on the cross-section through the initiation site indicated a surface hardness of 56 HRC at the fracture site.

Two comparison input shafts (No. XX and No. XX cars from XXXXXXXXX, respectively) were received for comparative analysis. The components were subjected to fluorescent penetrant testing per MTI in-house operational procedures for informational purposes (generally according to ASTM E165-95). No cracking was observed.

**Figure 22** provides a close-up view of the No. XX car input shaft at the date code location. The dot peen marked lettering indicates the shaft is of the same manufacture date as the fractured input shaft. Chemical analysis of the comparison input shaft indicates the component is manufactured from 300M, ultra-high strength, alloy steel. Table 1 provides the elemental composition of the part.

Rockwell hardness testing of the No. xx comparison input shaft at the mid-radius indicates an average core hardness of 55 HRC.

**Figure 23** provides a close-up view of the second comparison input shaft (No. xx car) at the date code location. The dot peened lettering indicates the shaft is of a different manufacture date when compared to the fractured input shaft.

Chemical analysis of the comparison input shaft indicates this component is manufactured from SAE 9310, high strength, carburizing alloy steel. The splined region of the part is likely to be carburized. Table 2 provides the elemental composition of the part.

Rockwell hardness testing of the No. xx comparison input shaft at mid-radius indicates an average core hardness of 38 HRC. The 9310 shaft exhibits a much higher degree of toughness and decreased notch sensitivity in the shaft region which is masked during the carburizing treatment.

**CONCLUSIONS:**

The component fractured due to dot peen marking of the shaft, creating a high stress concentration in the hard (54 HRC) 300M, ultra-high strength, alloy steel part. An intergranular fracture zone was noted, initiating at the bottom of dot peen marked lettering on the OD surface of the shaft. Two fatigue events covering approximately 33% of the fracture surface were noted adjacent to the region of intergranular fracture initiation, prior to final torsional overload failure of the component.

Secondary, incipient intergranular cracking was observed at the bottom of adjacent dot peened lettering.
The high hardness of the shaft makes the component highly notch sensitive. The dot peen machined lettering provided an initiation site for fracture initiation. The initial region of brittle intergranular cracking indicates a brittle surface condition and possibly high residual stresses in the surface of the shaft.

Hardness testing and chemical analysis of two additional input shafts, indicated the component from the No. xx car was manufactured from 300M ultra-high strength steel with an average hardness value of 55 HRC. The second input shaft from the No. xx car was manufactured from SAE 9310 high strength alloy steel with an average core hardness of 38 HRC. The shaft splines are likely carburized in the 9310 material.

**CHEMICAL ANALYSIS**

**Table 1**
Chemical Analysis of No. XX Car (Fractured) and No. XX Car (Comparison) Input Shafts

<table>
<thead>
<tr>
<th>Element</th>
<th>Fractured Input Shaft (wt. %)</th>
<th>Comparison Input Shaft (wt. %)</th>
<th>300M Steel Specification (wt. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0.41</td>
<td>0.43</td>
<td>0.40 – 0.46</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.71</td>
<td>0.71</td>
<td>0.65 – 0.90</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.011</td>
<td>0.010</td>
<td>NA</td>
</tr>
<tr>
<td>Sulfur</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>NA</td>
</tr>
<tr>
<td>Silicon</td>
<td>1.50</td>
<td>1.53</td>
<td>1.45 – 1.80</td>
</tr>
<tr>
<td>Nickel</td>
<td>1.90</td>
<td>1.91</td>
<td>1.65 – 2.0</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.73</td>
<td>0.74</td>
<td>0.70 – 0.95</td>
</tr>
<tr>
<td>Molybdenium</td>
<td>0.40</td>
<td>0.40</td>
<td>0.30 – 0.45</td>
</tr>
<tr>
<td>Vanadium</td>
<td>0.07</td>
<td>0.07</td>
<td>0.05 min</td>
</tr>
</tbody>
</table>

Both input shafts meet specification for 300M, ultra-high strength, alloy steel.

**Table 2:**
Chemical Analysis of No. XX Input Shaft

<table>
<thead>
<tr>
<th>Element</th>
<th>Fractured Input Shaft (wt. %)</th>
<th>SAE 9310 Specification (wt. %)</th>
</tr>
</thead>
</table>
The No. XX car input shaft meets specification for SAE 9310 high strength, alloy steel.

### IMAGES:

**Figure 1:** An overview of the fractured input shaft (top) and two comparison shafts that had undergone racing at XXXXXXXXX. (Photo PB2551)

**Figure 2:** A close-up view of the fractured input shaft. The fracture crosses the "0" in the date code stamp on the part (arrows). (Photo PB2552)

**Figure 3:** A closer view of the fractured input shaft's fracture. (Photo PB2552)

**Figure 4:** A low angle view of the...
input shaft. The fracture crosses the "0" in the date stamp on the part (arrows). (Photo PB2553)

fractured input shaft. The arrows point to the fracture origin at the dot peened "0" in the date code. (Photo PB2554)

**Figure 5:** A closer slightly different low angle view of the fracture initiation site (arrow). (Photo PB2555)

**Figure 6:** A close-up view of the fracture surface. The blue arrow points to the fracture origin at a brittle intergranular zone. Two fatigue zones are observed propagating over approximately 33% of the fracture surface prior to final torsional overload. Fatigue arrest marks and oxidation are noted in fatigue zone 2. (Photo PB2556)

**Figure 7:** A low magnification SEM view of the facture surface in the region of fracture initiation. Intergranular fracture, indicative of a high hardness, brittle condition is noted at the fracture origin. The boxed region is detailed at increased magnification in Figure 8. (SEM Photo 2S7404, Mag: 5X)

**Figure 8:** An increased magnification SEM view of the Boxed region in Figure 7. The arrow indicates the approximate fracture initiation site shown at increased magnification in Figure 9. (SEM Photo 2S7406, Mag: 45X)
**Figure 9:** An increased magnification SEM view of the fracture surface. Intergranular fracture, indicative of a high hardness, brittle condition is noted at the fracture origin. The boxed region is detailed at increased magnification in Figure 10. (SEM Photo 2S7407, Mag: 5X)

**Figure 10:** A high magnification SEM view of the fracture origin indicates the fracture initiated at the bottom of a dot peen indentation on the shaft OD surface. (SEM Photo 2S7408, Mag: 500X)

**Figure 11:** A low magnification SEM view of the shaft OD surface at the fracture origin (arrow). The initiation site is at the date code engraving on the shaft. (SEM Photo 2S7410, Mag: 20X)

**Figure 12:** An increased magnification SEM view of the fracture origin (arrow) in reference to the OD surface and the date code stamping of the shaft. Fracture initiated at the vertical line of the "0". The brittle, intergranular region, adjacent to the fracture initiation site is observed. (SEM Photo 2S7411, Mag: 50X)
Figure 13: A high magnification SEM view of the fracture origin at the vertical "0". (SEM Photo 2S7412, Mag: 200X)

Figure 14: A SEM/BSE image of the same areas is shown in Figure 13. The BSE image more clearly reveals secondary cracking in the bottom of the dot peen machined letter. (SEM/BSE Photo 2S7413, Mag: 200X)

Figure 15: A low magnification SEM/BSE image of an adjacent letter ("I") on the shaft OD. The boxed region appears at increased magnification in Figure 16. (SEM/BSE 2S7414, Mag: 20X)

Figure 16: An increased magnification SEM view of the boxed region in Figure 15. Incipient cracking is observed in the boxed area shown at increased magnification in Figure 17. (SEM/BSE Photo 2S7415, Mag: 500X)
**Figure 17:** A high magnification SEM/BSE image of the boxed region in Figure 16 reveals incipient intergranular cracking (SEM/BSE Photo 2S7416, Mag: 2,500X)

**Figure 18:** An optical microscopic image of a longitudinal cross-section through the fracture origin. An impression in the surface at the fracture origin is the result of dot peen marking. An additional impression is observed below the fracture origin. (Photo D3913, Mag: 100X) (Photo PB2554)

**Figure 19:** A high magnification optical microscopic view of the longitudinal cross-section at the fracture origin. The fracture surface exhibits evidence of brittle intergranular fracture. No unusual conditions are observed in the martensitic microstructure. (Photo D3898M, Mag: 500X)

**Figure 20:** A high magnification view of the adjacent dot peen letter indentation in the shaft OD surface. A small, incipient, intergranular crack is observed at the bottom of the dot peen impression (more clearly shown in the unetched view in Figure 19). (Photo D3815M, Mag: 500X)
Figure 21: An increased magnification, un-etched view of the incipient crack noted in Figure 20. (Photo B3906, Mag: 1,000X)

Figure 22: A close-up view of the No. XX car input shaft. The dot peen lettering indicates the shaft is of the same manufacture date as the fractured input shaft. (Photo PB2558)

Figure 23: A close-up view of the No. XX car input shaft. The dot peen lettering indicates the shaft is of a different manufacture date than the fractured input shaft. (Photo PB2559)