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Metallurgical Analysis of Cracked Tool

Background

A cracked finger section was discovered in a plastic injection mold tool and sent to Tom Bertone for metallurgical failure analysis. A large crack had developed at the base of one finger. The tool is manufactured from a maraging steel. The metal was purchased from the mill in the solution annealed heat treat condition to accommodate machining. Following machining, the tool was given an age hardening heat treatment. The tool was placed into service and developed cracks at the base of a finger after about one year use. The metallurgical properties of this tool are to be evaluated for compliance to specification AMS 6514E.

Initial Observations and Procedures

The crack at the base of one finger is much larger than that of the first tool and appears to be filled with green injection molded plastic; see Figure 1. The crack is much larger and extends nearly across the base area of this finger. A section of the base was removed for microstructure analysis and microhardness testing (see arrow). The size of the crack provides an opportunity to open and examine the fracture surface using a scanning electron microscope.

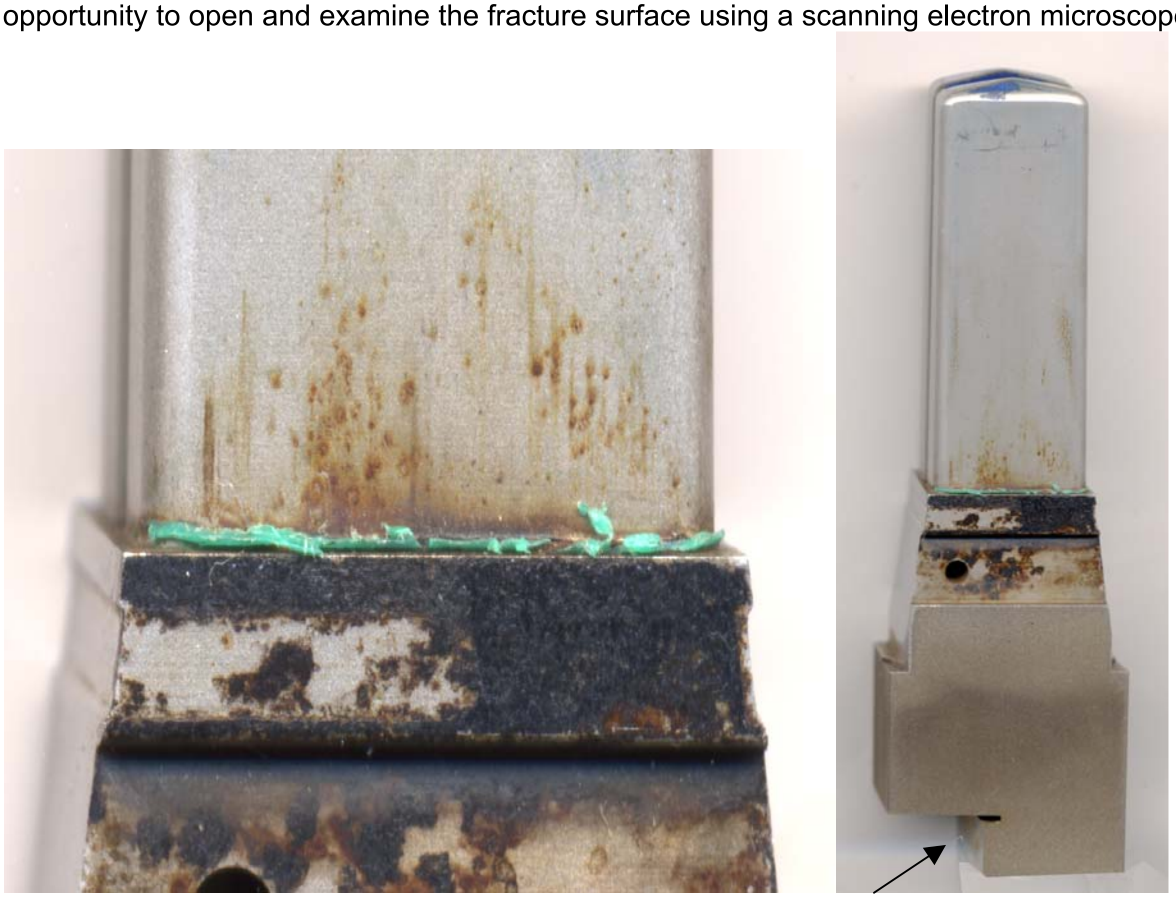


Figure 1. These photos show the condition of the finger as-received at TBC. The green plastic is lodged inside the crack as the base of one finger. The dark burnt areas appear to be residue from plastic and/or a mold release compound.

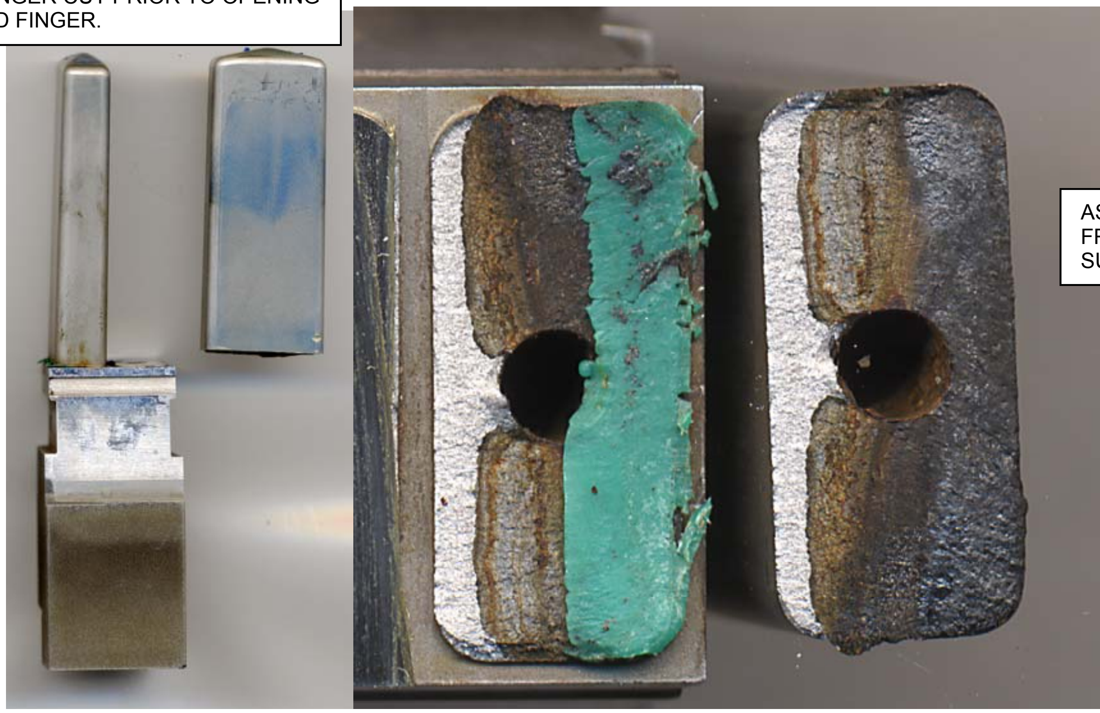


Figure 2. The uncracked finger was removed by wet sectioning as shown above. The base was clamped in a vice and the fracture finger was quickly bent to remove it; see bright silver fresh fracture. There is a pattern of progressive crack propagation on the fracture surface, evident buy rust colored corrosion. The black area appears burnt and smooth from plastic being injected and removed numerous times. Water has been leaking from the cooling hole; the interior of the hole is corroded. The coating of plastic was not bonded to the metal.

The fracture section (finger) was untrasonic cleaned in Micro™ , however, the black residue was not completely removed.

Figure 3. The arrow points to the location where fracture originated. The black carbon residue was scrubbed from the surface in order to see the fracture pattern. Fracture probably occurred due to notch sensitivity at the corner base of the finger or by sudden overload when processing parts.

Microstructure and Hardness Testing

The section removed from the base of the tool was prepared in accordance with standard ASTM procedures in order to compare the microstructure for compliance with AMS 6451E. A calibrated Tukon, Knoop microhardness tester was used to measure hardness,

Hardness Results: The measured hardness is 51.6 – 52.7HRC.

The microstructure was delineated with a 2% nital etch, observed on the optical microscope and photographed; see Figure 4.

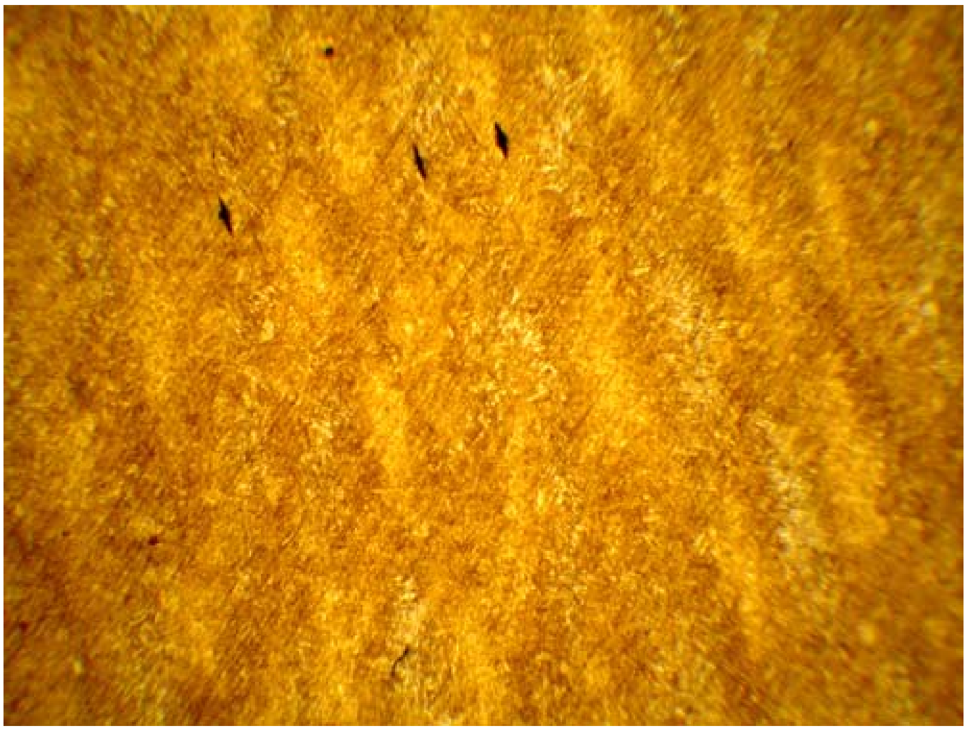
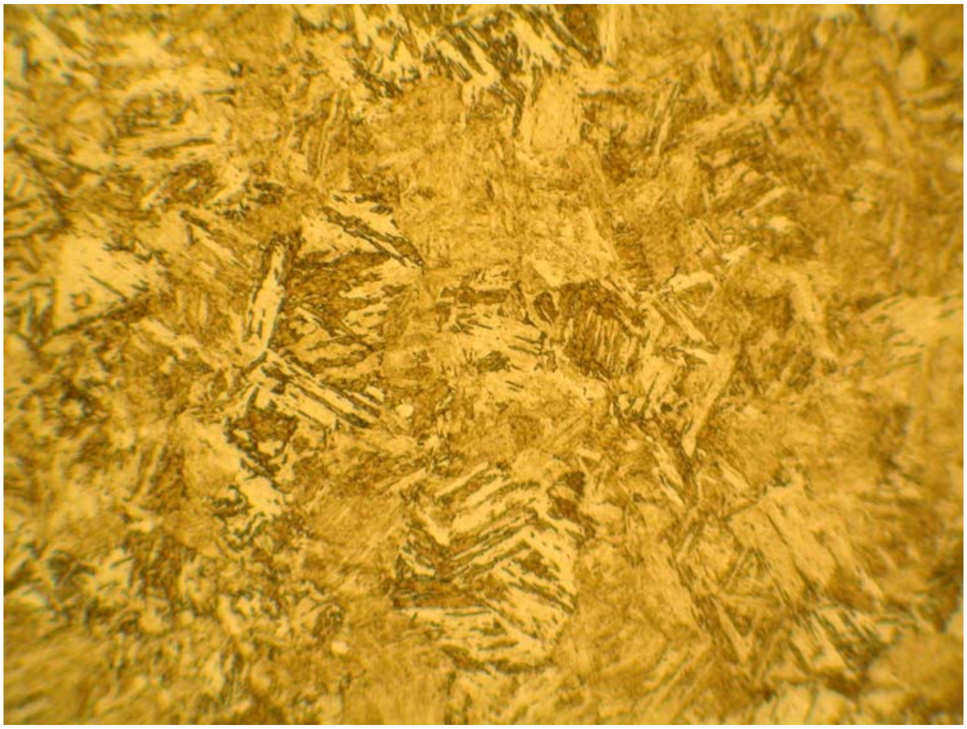


Figure 4. The microstructure exhibits a fine micro alloy segregation. However, this indicates the metal is not properly mill homogenized, or this pattern would not be present. The micro alloy segregation is the pattern of lighter colored blotchy areas. A properly homogenized steel exhibits a consistent color or etched texture across the surface. The Knoop microhardness indentations are also visible.

This section was re-polished and etched with Kalling's etch and photographed; see Figure 5 below. The measured grain size is predominately ASTM 3-5.

Discussion

Due to the burnt carbon deposit covering critical areas of the fracture surface, it was not possible to determine a fracture mode directly from the fracture surface without aggressively scrubbing. However, this was done, the pattern of fracture became clearer. The fracture origin is at a corner in the base radius. The crack progression appears to be caused by low cycle overstress and in simple terms, this means it appears the fracture began by impact and or sudden overstress by excess pressure. Upon cracking, the injection process was sufficiently forceful to cause the crack to grow quickly and propagate across the base of the finger. The tool began to leak once the cooling hole was compromised.



100X
Mag.
Kalling's
Etch

Figure 5. This is the microstructure of the second failed finger; compare to Figure 6., below from the first report,

It is possible to make a comparison between the original first fractured finger and the second cracked finger from the same tool. They appear metallurgically identical except for the cell size of the micro alloy segregation. If this steel were subjected to another solution annealing, the grain size would be dramatically reduced in size.

Recommendation

Although the steel is purchased in the solution annealed condition, it would be wise to redo the solution anneal heat treat before machining.

Conclusion

In the opinion of this metallurgist, the most likely cause of the crack is overpressure during operation of the tool. The fracture sensitivity and/or fracture toughness of the metal was not optimized, due to an insufficient or deficient Mill solution annealing heat treatment. The steel was purchased under the requirements of AMS 6514, however, the material supplier or the Mill, delivered steel which did not meet those requirements.

Respectfully Submitted,

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