SUMMARY:

A cracked XXXXX polymer filament die plate was received for analysis to determine the cause of cracking. Results indicate the die plate cracked as a result of a brittle nitrided case and an insufficient cross-sectional area of the narrow ligament between the cap screw hole and the heater cartridge hole on the inlet face. Cracking initiated at the cap screw hole and propagated to the heater hole and beyond in a rapid manner. The heating of the inserted heater cartridge caused thermal stress on the adjoining thin ligament (cap screw wall) resulting in cracking of the extremely hard and brittle nitrided case.

Metallographic examinations revealed multiple cracks in the nitrided case along all of the cap screw holes. Microhardness testing at approximate depths of 0.002-in. revealed an extremely high and brittle hardness value of 81 to 84 Rockwell C (HRC). The core hardness of the die plate was 44 HRC.

Chemical analysis identified the die plate material as XXXXXXXXX, a powder metal, martensitic stainless tool steel designed for exceptionally good wear resistance.
Alloy XXXXXX exhibits superior wear resistance due to the high volume of carbides, especially vanadium carbides (which are the most wear resistant common tool steel carbides) and should provide satisfactory service without nitriding. Gas nitriding also reduces the corrosion resistance of the component as well as the hardness of the matrix.

It is recommended that the die plate not be nitrided. The die plate should be double tempered at 700° F immediately after quenching, which results in a higher hardness and improved corrosion resistance. It is also recommended that the cap screw hole be moved farther from the heater cartridge hole to increase the thickness between these two. Slower heat up of the heater cartridges would also aid in reduced thermal stresses during start-up.

**ANALYSIS:**

A cracked XXXXXX die plate was received for analysis to determine the cause of cracking. It was reported the die plate was a new material for this application and was found cracked after approximately only 30 minutes of service. A second similar die plate was reported to have cracked during heat-up.

**Figure 1** is a photo of the die plate outlet face in the as-received condition. Cracking was subsequently found to have initiated near the outer edge on the opposite face and progress inward, then circumferentially connecting the extrusion holes. **Figure 2** is a side view of the die plate displaying the crack width. The wide crack indicates high residual stress within the part.

**Figure 3** is a photo of the die plate inlet face in the as-received condition. Cracking was found to have initiated at the thin ligament between the cap screw hole and heater cartridge hole.

**Figure 4** is a close–up photo of the crack initiation site between the cap screw hole and the heater cartridge hole. The cap screw hole is very close to the heater cartridge hole with only a very thin ligament separating the two.

**Figures 5 and 6** show other close-up examples of cracking between the cap screw hole and the heater cartridge hole around the inlet surface. Low magnification examination using a stereomicroscope (65X max.) revealed all 12 cap screw/heater cartridge ligaments were cracked in a similar manner.

Due to the severely oxidized crack surfaces condition, a total of three separate cracks between the cap screw hole and the heater cartridge hole from different locations were opened for examination. **Figure 7** presents the second opened crack representing the typical narrow wall (ligament) between the cap screw hole and heater cartridge hole.
The third opened crack was shorter and not as severely oxidized, exhibiting the best fracture surface condition. This sample was cleaned and examined at high magnification analysis using a scanning electron microscope (SEM).

**Figure 8** is a low magnification SEM image of the opened crack surface between the cap screw and heater hole at the inlet face. The original crack fracture surface is outlined. The remaining fracture surface is the result of the laboratory overload due to forcing the crack open.

Increased SEM magnification using back scatter electron (BSE) imaging in **Figure 9** reveals the original crack surface is oxidized. (The BSE image is more sensitive to compositional and topographical variations. Low atomic number (light) elements are darker and high atomic number (heavy) elements are lighter in the image).

**Figure 10** is an increased magnification SEM image of the crack initiation region revealing the nitrided case which borders the fracture surface. The surface morphology indicates the crack initiated from the upper right corner in the notch formed by a partial thread root (highest stress concentration). Several regions on the opened crack surface are presented at higher SEM magnifications in subsequent figures.

**Figure 11** presents a high magnification SEM image of the fracture through the nitrided case. The case surface is oxidized, which masks the true fracture surface features. The high magnification SEM image in **Figure 12** displays the fracture surface below the nitrided case which is also highly oxidized. **Figure 13** presents a high magnification SEM image of the laboratory opened fracture surface. The non-oxidized fracture exhibits a dimpled morphology, indicative of ductile overload. This indicates the core material is not embrittled.

One of the fine cracks between the cap screw hole and the heater cartridge hole (see **Figure 6**) was cut-out for metallographic analysis. The inlet face was polished to remove approximately 0.002-inches from the surface. The sample was then prepared for metallographic analysis in accordance with ASTM E3-01. Etching in accordance with ASTM E407-99 revealed the microstructure that was examined using an optical microscope in accordance with ASTM E883-02.

**Figure 14** is a low magnification optical photomicrograph of the cracked narrow ligament between the cap screw hole and heater cartridge hole. The cross-section is within the nitride case microstructure. The ligament thickness is only 0.028-in. (721.9 microns) thick at this location. Multiple cracks are observed. An increased magnification photomicrograph of one of the tight cracks (**Figure 15**) reveals corrosion along the cap screw hole edge and an oxide lined crack. The crack is at a small machining notch at the hole edge. A very high concentration of carbides is observed in the microstructure.
The sample surface was re-ground and polished to a depth of approximately 0.025-in. and etched to re-examine the microstructure. **Figure 16** is a low magnification optical photomicrograph of the cross-section at a depth of 0.025-in. below the inlet surface. A uniform nitrided case is observed along the hole surfaces.

The increased magnification photomicrograph in **Figure 17** reveals cracks at machining notches along the cap screw hole ID surface (unetched to resolve the fine cracking). The same location is presented in the etched condition in **Figure 18** revealing the dark nitride diffusion zone (case). The white spherical particles in the microstructure are carbides.

**Figure 19** is a high magnification optical image of the nitrided case. The white spherical particles in the microstructure are carbides. The elongated white network along the grain boundaries are iron nitrides and carbonitrides, which result in an embrittled case structure.

A longitudinal cross-section along a cracked cap screw hole from the inlet surface (parallel to the crack) was also sectioned for metallographic analysis. **Figure 20** is a low magnification optical image of the cross-sectioned sample revealing cracking in the nitride case on the inlet face and in the threads. A higher magnification view of the inlet face cracks in **Figure 21** reveals the intergranular nitride/carbonitrides network in the nitride case.

**Figure 22** is a low magnification optical image of the longitudinal cross-section along the cap screw hole. Severe cracking and chipping are observed in the nitrided case on the threads. **Figure 23** presents the cracking in the nitrided case in the threads at increased magnification. The severity of the cracking indicates a very brittle nitrided case.

**Microhardness testing** (ASTM E384-99e1) was performed across the longitudinal cross-sections at fine increments below the inlet surface. Microhardness readings were converted from Knoop 500-gram load to Rockwell C (HRC) using ASTM E140-02. Results revealed an extremely high and brittle case hardness of 81 to 84 HRC. The core hardness of the die plate was 44 HRC. A profile of the microhardness test results is presented in **Figure 24**.

The low hardness of the die plate core indicates the part was tempered and or gas nitrided well over 1000o F, which significantly reduces the corrosion resistance of the material. Nitriding alone also reduces the corrosion resistance.

**CHEMICAL ANALYSIS**

Table 1
Spectrographic chemical analysis was performed on the die plate material using an optical emission spectrometer in accordance with ASTM E415-99a. Results indicate the component is manufactured from xxxxxxx, a powder metal, martensitic stainless tool steel designed for exceptional wear resistance and high corrosion resistance.

CONCLUSIONS:

The die plate cracked as a result of a brittle nitrided case and an insufficient cross-sectional area of the narrow ligament between the cap screw hole and the heater cartridge hole on the inlet face. Cracking initiated at the cap screw hole and propagated to the heater hole and beyond in a rapid manner. The heating of the inserted heater cartridge caused thermal stress on the adjoining thin ligament (cap screw wall) resulting in cracking of the extremely hard and brittle nitrided case. Nitriding also reduces the corrosion resistance and hardness of the die plate.

It is recommended that the die plate not be nitrided. The die plate should be double tempered at 700° F immediately after quenching, which results in a higher hardness and improved corrosion resistance. It is also recommended that the cap screw hole be moved farther from the heater cartridge hole to increase the thickness between these two. Slower heat up of the heater cartridges would also aid in reduced thermal stresses during start-up.

IMAGES:

**Figure 1:** A photo of the die plate outlet face in the as-received condition. Cracking initiated near the outer edge (larger red arrow) and progressed inward, then circular connecting the extrusion holes, running

**Figure 2:** A side view of the die plate displaying the crack width in the area of initiation. The wide crack indicates high residual stress within the part.
to each end of the ruler (yellow arrows).

**Figure 3:** A photo of the die plate inlet face in the as-received condition. The main crack initiated at the boxed-in area shown in a closer view in Figure 4.

**Figure 4:** A close-up photo of the crack initiation site (red arrow) which is the thin ligament between the small cap screw hole and the larger heater cartridge hole. The cap screw hole is very close to the heater cartridge hole, only a thin cross-section separates the two.

**Figure 5:** A close-up example of cracking between the cap screw hole and the heater cartridge hole around the inlet surface (arrow).

**Figure 6:** Close-up view of another crack between the cap screw hole and the heater cartridge hole on the inlet surface (arrow). Low magnification examination using a stereomicroscope revealed all 12 cap screw/heater cartridge ligaments were cracked.
Figure 7: View of the second opened crack representing the typical wall thickness (narrow ligament) between the cap screw hole and heater cartridge hole.

Figure 8: Low magnification SEM/BSE image of a third opened short crack along the cap screw at the inlet face. The original short crack zone is outlined. The remaining fracture surface is the result of laboratory overload to force the crack open. (SEM/BSE Photo 2S7349, Mag. 25X)

Figure 9: Increased SEM magnification using back scatter electron (BSE) imaging reveals the original crack surface is oxidized (darker surface region). (SEM Photo 2S7351, Mag. 50X)

Figure 10: Increased magnification SEM image of the opened crack initiation region revealing the nitride case around the fracture surface. The surface morphology indicates the crack initiated from the partial thread root (highest stress concentration at red arrow). The boxed in areas are presented at higher SEM magnifications in subsequent figures. (SEM Photo 2S7354, Mag. 125X)
**Figure 11:** A high magnification SEM image of the opened crack in the nitride case area indicated in Figure 10. The surface is oxidized, masking the original features. (SEM Photo 2S7355, Mag. 1,500X)

**Figure 12:** The high magnification SEM image of the original crack through the core region indicated in Figure 10 is also highly oxidized. (SEM Photo 2S7357, Mag. 1,500X)

**Figure 13:** A high magnification SEM image of the laboratory opened fracture surface area indicated in Figure 10. A non-oxidized dimpled morphology, indicating ductile overload is revealed. (SEM Photo 2S7356, Mag. 1,500X)

**Figure 14:** Low magnification optical photomicrograph of the cracked cap screw/heater cartridge ligament approximately 0.002-in. below the inlet surface. The ligament thickness is only 721.9 microns (0.028-in.) thick at this location. Multiple cracks (yellow arrows) are also observed. (Photo D3686, Mag. 50X, Nital etch)
Figure 15: A high magnification photomicrograph reveals corrosion along (small arrows) an oxide lined crack at a notch at the cap screw hole edge. The white particles in the microstructure are carbides. (Over-Exposed Photo D3690M, Mag. 500X, Nital etch)

Figure 16: Low magnification optical photomicrograph of the re-ground surface (approximately 0.025-in. below the inlet face) shown in Figure 14 displays a uniform nitride case. Several rough machining notches are noted along the cap screw hole. (Photo D3797, Mag. 50X, Nital etch)

Figure 17: Increased magnification photomicrograph reveals cracks at rough machining notches along the cap screw hole ID surface. (Photo D3795, Mag. 200X, unetched)

Figure 18: The same location as Figure 17 is presented in the etched condition revealing the dark nitride diffusion zone (case). The white particles in the microstructure are carbides. (Photo D3798, Mag. 200X, Nital etch)
Figure 19: A high magnification optical image of the nitride case. The white spherical particles in the microstructure are carbides. The elongated thin white structure is a network of iron nitride/carbonitrides along boundaries, resulting in an embrittled case. (Photo D3707M, Mag. 1,000X, Nital etch)

Figure 20: Low magnification optical photomicrograph image of the longitudinal cross-section along a cap screw hole reveals cracking (arrows) in the inlet face and in the nitrided case on the threads. The boxed area is shown at high magnification in Figure 21. (Photo 2MA3787, Mag. 50X, Nital etch)

Figure 21: High magnification optical photomicrograph reveals the intergranular white nitride network in the cracked outer case. The white spherical particles in the microstructure are carbides. (Photo 2MA3793M, Mag. 500X, Nital etch)

Figure 22: Low magnification optical photomicrograph of the longitudinal cap screw hole cross-section. Severe cracking and some chipping are observed in the nitride case on the threads (arrows). (Photo 2MA3788, Mag. 50X, Nital etch)
Figure 23: Higher magnification optical photomicrograph showing the severity of cracking in the nitrided case in the cap screw hole threads. (Photo 2MA3790, Mag. 500X, Nital etch)

Figure 24: A microhardness profile of the nitrided case of the die plate. A very high hardness brittle case is indicated.