M. E. Williams and Associates, Inc.

"Excellence in Metallurgical Engineering"

12825 385th Avenue
Waseca, MN 56093

Case Study: Locking Pawl and Gear Evaluation

By

Merlin E. Williams, P.E.

Subject

A broken Locking Pawl and Gear, parts of a safety device were examined. The design, fabrication, and heat treatment of safety devices requires a good knowledge of materials, processes, and process control. The two parts were examined to determine the grade of steel used, and the type of heat treatment. The examination was done by chemical analysis, hardness testing, and metallographic examination. The metallographic examination revealed defective heat treating, which was a critical safety concern with these parts.

Chemical Analyses

Chemical analyses were done according to the following ASTM Specifications: E1019 for carbon and sulfur, and E415 for other elements. The results of the analyses are given in the table the follows.

Chemical Analysis (Percent by Weight)		
Element	Pawl	Gear
Carbon	0.18	0.19
Manganese	0.74	0.62
Phosphorous	0.008	0.005
Sulfur	0.034	0.034
Silicon	0.20	0.19
Nickel	0.07	0.08
Chromium	0.08	0.07
Molybdenum	0.01	0.01
Copper	0.27	0.29

The chemical analysis showed that both the pawl and gear were fabricated from AISI/SAE 1018 steel.

Hardness Testing

The hardness testing was done according to ASTM E384, using a Knoop indenter and a 500 gram load. The results are given in the following tables.

Hardness Test Data - Core Hardness (Rockwell C Scale)					
Sample	KNOOP	STD DEV	MAX VALUE	MIN VALUE	HARDNESS
Pawl	266.00	20.02	294.00	246.00	25.00 RC
Gear	242.00	12.60	256.00	223.00	20.50 RC

The core hardness indicated that the yield strength of the steel used for the pawl and gear was between 95,000 and 100,000 psi.

Hardness Profile – Case (Rockwell C Scale)		
Depth	Pawl	Gear
0.002	51.10	50.10
0.004	52.70	52.90
0.008	51.70	53.10
0.012	51.30	51.20
0.016	50.10	51.20
0.020	48.90	51.30
0.024	48.50	49.90
0.028	45.70	50.90
0.032	46.60	47.10
0.036	42.20	48.30
0.040	40.70	46.80

The hardness profile showed that the effective case depth was approximately 0.020 of an inch. Visual measurements showed that the total case depth was approximately 0.060 of an inch. The hardness of the case near the surface was in the low 50 Rockwell C range, indicating yield strength of around 200,000 psi, and that the parts had been tempered to a lower than normal hardness to improve toughness of the case. Typically, case hardening of 1018 steel is only done to improve wear resistance, with the total case depth of around 0.006 of an inch. This case depth was ten times deeper at 0.060 of an inch.

Metallographic Examination

Figure 1 shows the carburized case of the pawl. The large grains in the case indicated that the carburizing process had been done at a very high temperature. Normally, the grains in a carburized case are not distinguishable at 400X, let alone 100X.

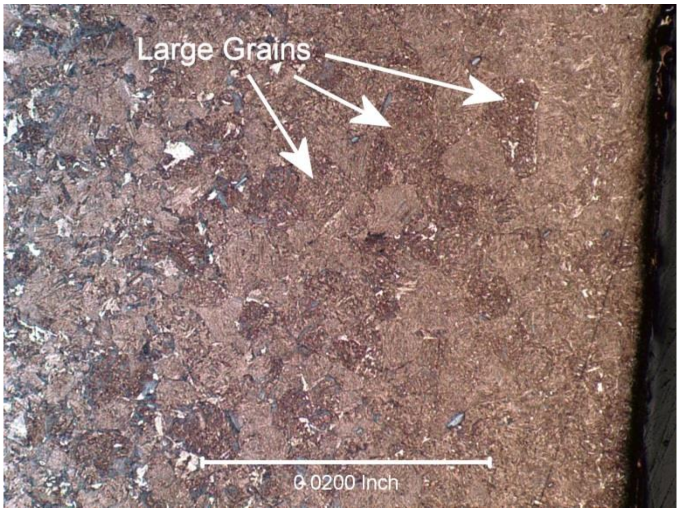

Figure 1 – 100X Carburized Case of Pawl

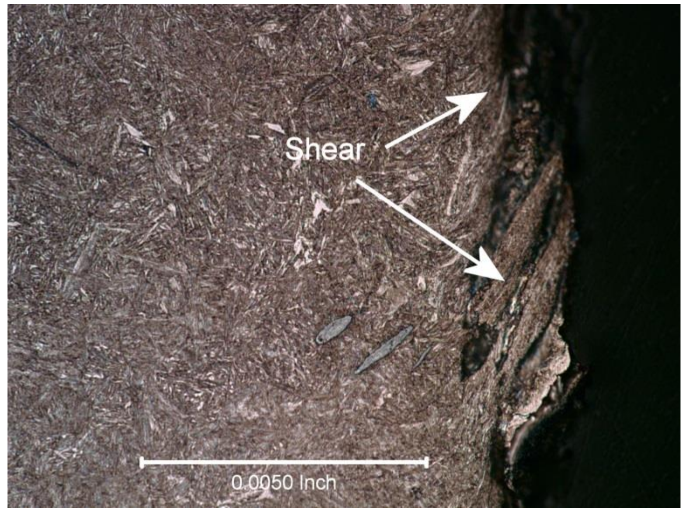

Figure 2 – 400X Shear in Pawl Wear Area

Figure 2 shows shearing of the carburized steel on the locking pawl wear face. The stress required to cause shearing of the carburized case is approximately 200,000 psi. The stress on the face of the pawl was equal to, or greater than, the yield strength of the heat treated 1018 steel of the locking pawl.

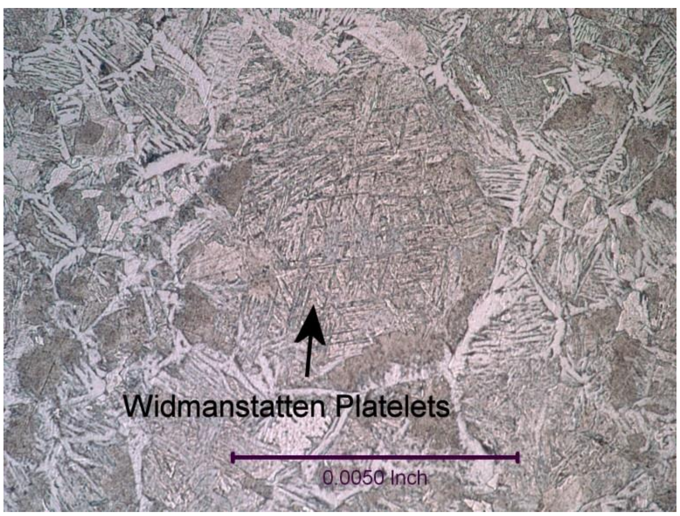

Figure 3 – 400X Widmanstatten Platelets - Core Microstructure of Pawl

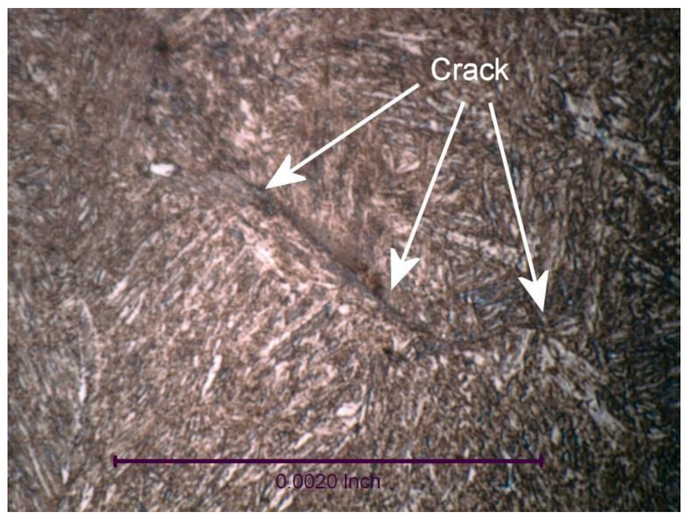

Figure 4 – 1500X Intergranular Cracking in Pawl's Carburized Case

Figure 3 shows a large grain in the core of the pawl which contained Widmanstatten platelets. Widmanstatten does not form in steel at temperatures lower than 2000º F., and typically forms at temperatures above 2200º F. Widmanstatten is a very brittle structure, and is not acceptable for any reason in a steel part. The maximum carburizing temperature for steels is 1900º F., and this is rarely done because excessive grain growth will weaken the carburized case. For that reason, the usual maximum carburizing temperature is 1700º F. The presence of Widmanstatten and the large grain size indicated that the pawl was carburized at a temperature in excess of 2200º F.

Figures 4 and 5 show intergranular cracking in the locking pawl's carburized case. The likely cause of the cracking was the large grain size that resulted from the excessive carburizing temperatures. Small cracks, resulting from the large grain size, will weaken the parts, and are too small to be detected by non-destructive test methods.

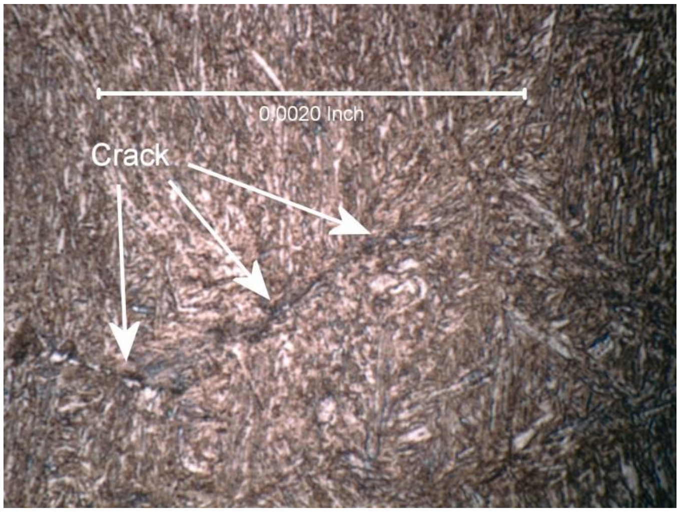

Figure 5 – 1500X Intergranular Cracking in Pawl's Carburized Case

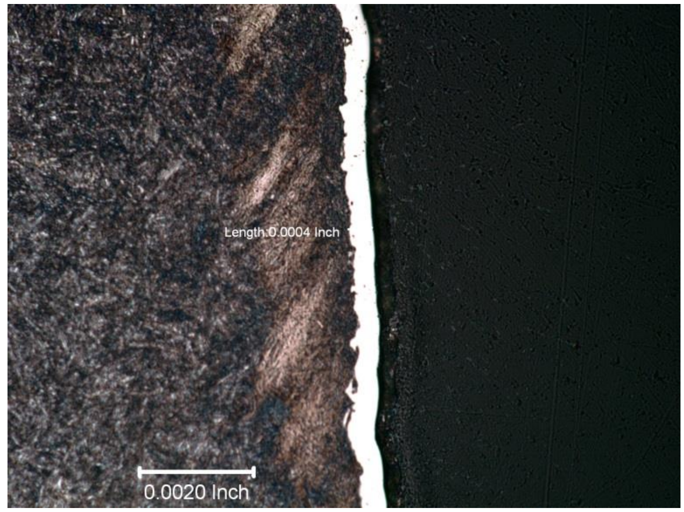

Figure 6 – 400X Nickel Plating on Pawl Surface

Figure 6 shows 0.0004 of an inch of nickel plating on the surface of the pawl. The purpose of the nickel plating was to prevent corrosion of the steel, which could result in hydrogen embrittlement, leading to intergranular fracture. If the nickel plating had been done electrolytically, the fine intergranular cracking found was likely the result of hydrogen embrittlement. Conversely, if the plating used was electroless nickel plating, then the fine intergranular cracks were the result of another factor, like delayed quench cracking.

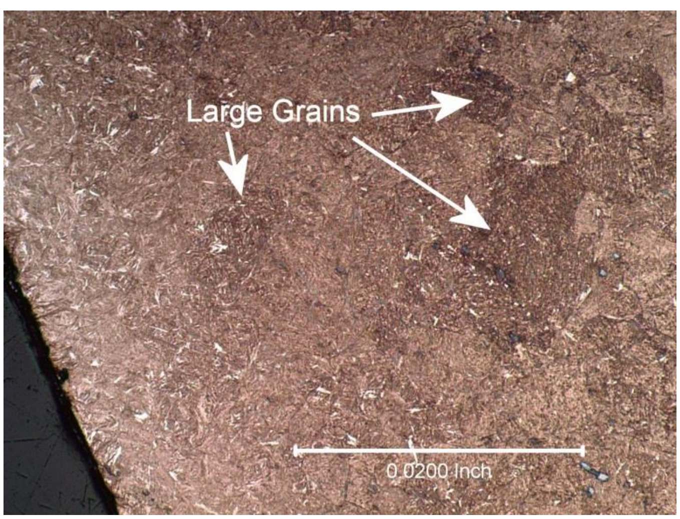

Figure 7 – 100X Carburized Case of Gear

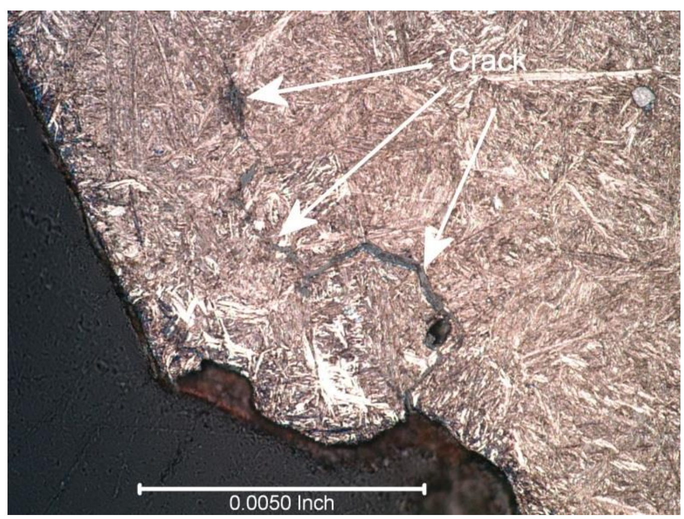

Figure 8 – 400X Intergranular Fracture of Gear

Figure 7 shows large grains in the carburized case of the gear. The large grains were the result of excessive carburizing temperature.

There was a chip in one of the gear teeth. The fracture mode associated with this chipping was intergranular fracture, Figure 8. A quality carburized case should not fail, but if it does, the fracture mode should be ductile rupture.

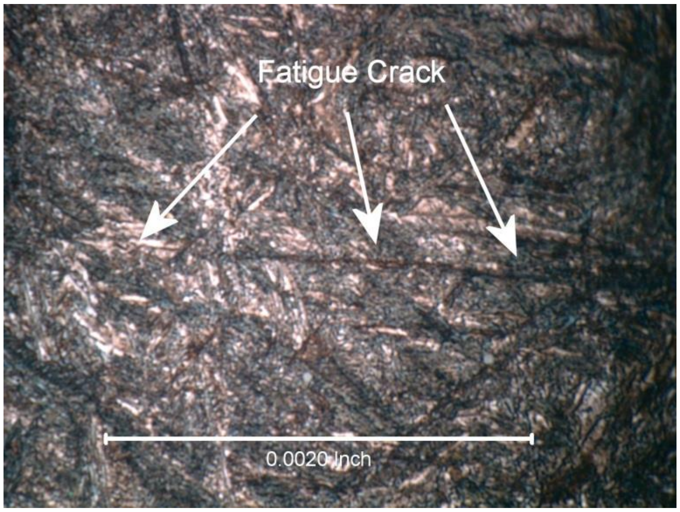

Figure 9 – 1500X Fatigue Crack in Gear

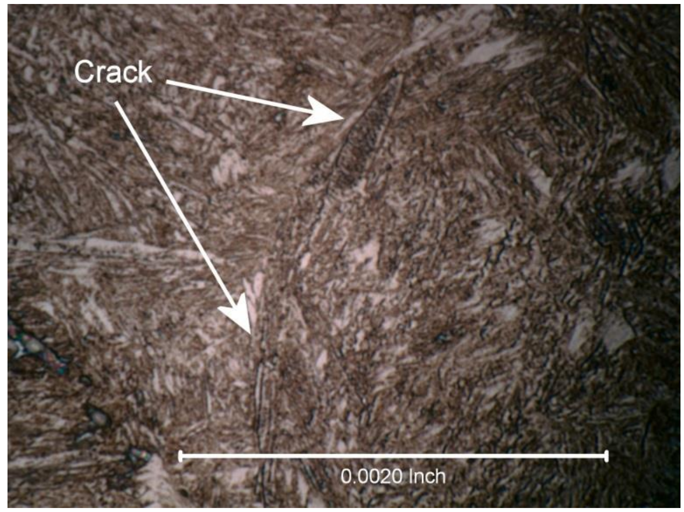

Figure 10 – 1500X Intergranular Cracking in Gear's Carburized Case

Figure 9 shows the initiation of a fatigue crack originating from the wear surface on the gear tooth face. The fatigue strength of the carburized case is about 100,000 psi. The presence of a fatigue crack indicates that the stress on the gear teeth was higher than 100,000 psi.

Figure 10 shows intergranular cracking in the gear's carburized case.

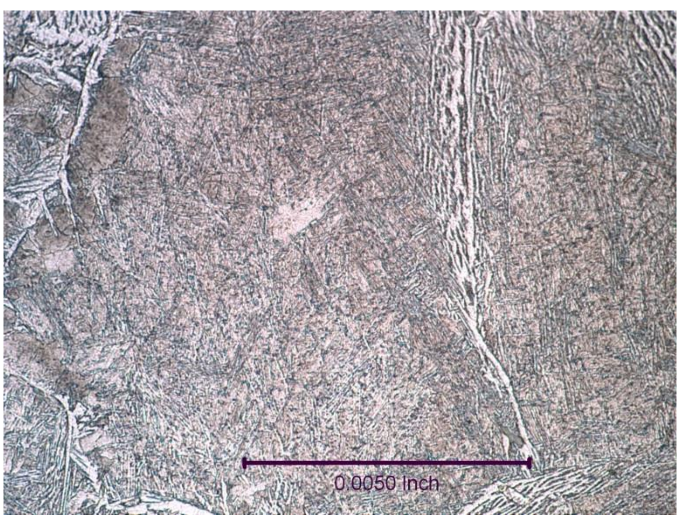

Figure 11 – 400X Large Grains in Gear Core

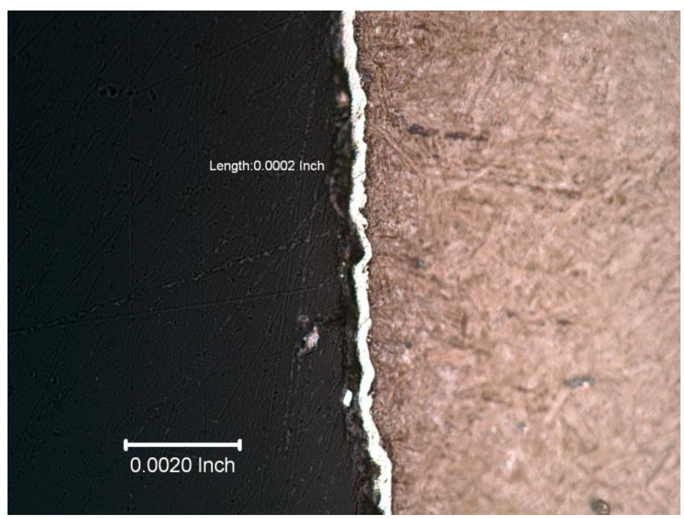

Figure 12 – 400X Nickel Plating on Gear

Figure 11 shows excessive grain size in gear core material, indicating excessive carburizing temperature.

The thickness of the nickel plating on the gear was 0.0002 of an inch.

Based on the findings given in this report, all pawls or gears needed to be replaced at once.

Conclusions

1. The locking pawl and gear were fabricated from 1018 steel.

2. The pawl and gear were carburized to an effective case depth of about 0.020 inch, with a total case depth of 0.060 inch.

3. The locking pawl and gear were carburized at excessively high temperatures, exceeding 2000º F.

4. The locking pawl contained Widmanstatten grains, indicating exposure to temperatures in excess of 2200º F.

5. The locking pawl and gear had excessively large grain size in the carburized case and core.

6. The locking pawl and gear had intergranular fracture in the carburized case due to excessively large grain size, and possible hydrogen embrittlement resulting from nickel plating.

7. The shear and fatigue loading on the pawls exceeded the shear strength and fatigue strength of the carburized case.

8. The locking pawl and gear were nickel plated.

Recommendations

1. Replacements of locking pawls and gears to be fabricated from 8620 steel.

2. Replacement locking pawls and gears to be carburized to a 0.030 to 0.035 inch effective case depth, with a case hardness between 55 and 60 Rockwell C Scale. The pawls and gears to be cold treated to minus 100º F. prior to final tempering to insure a carburized case free from retained austenite detectable at 400X or 500X magnification.

3. Plate the locking pawls and gears with electroless nickel plating to a thickness range of 0.0002 to 0.0005 inch.

4. All locking pawls and gears to be frequently inspected for cracks and chipping.

These defective parts had to be considered as a critical safety concern.

It was also my recommendation that in order to prevent a major failure or any injury due to breakage of a lug on a locking pawl or gear, all Locking Pawls and Gears needed to be replaced at once.