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Case Study: Locking Clamp Failure

By

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Subject

Examination of three Locking Clamps to determine the cause of failure. The clamps were machined from 12L14 steel. The failed clamps were examined by visual examination, hardness testing, metallographic examination, and fracture mechanics.

Visual Examination

Figure 1 – Crack in Lug, Locking Clamp 1

Figure 2 – Visual Indication of Brittle Fracture in Locking Clamp 1

Figure 3 –Locking Clamp 2

Figure 4 –Locking Clamp 3

Figures 1 and 2, show Locking Clamp 1 and the fracture of one of the lugs, which was clearly brittle fracture, as can be seen in Figure 2.

Figure 3 shows Locking Clamp 2. The fracture mode of this clamp was also brittle fracture. The metallographic cross section of this clamp was made through the intact lug.

Locking Clamp 3 is shown in Figure 4. The fracture mode of this clamp was also clearly brittle fracture. The metallographic cross section of the clamp was made through the intact lug. The condition of the plating on the surface indicates that the Locking Clamps had not been used more than a few times.

Forces applied to the locking lugs of the Locking Clamps result in stress perpendicular to the rolling direction, such as shear, parallel to the direction of rolling.

Hardness Testing

The hardness testing was done according to ASTM E384, using a Vickers indenter and a 500 gram load. The results of the testing are given in the table that follows.

Hardness Test Data **(Rockwell B Scale)**					
Location	Vickers	STD DEV	MAX VALUE	MIN VALUE	HARDNESS
Clamp 1	197.00	17.62	223.00	176.00	92.18 RB
Clamp 2	182.00	8.11	191.00	171.00	89.16 RB
Clamp 3	190.00	12.50	211.00	178.00	91.04 RB

The hardness test data showed the Locking Clamp steel was within the normal hardness range for 12L14 steel.

Metallographic Examination

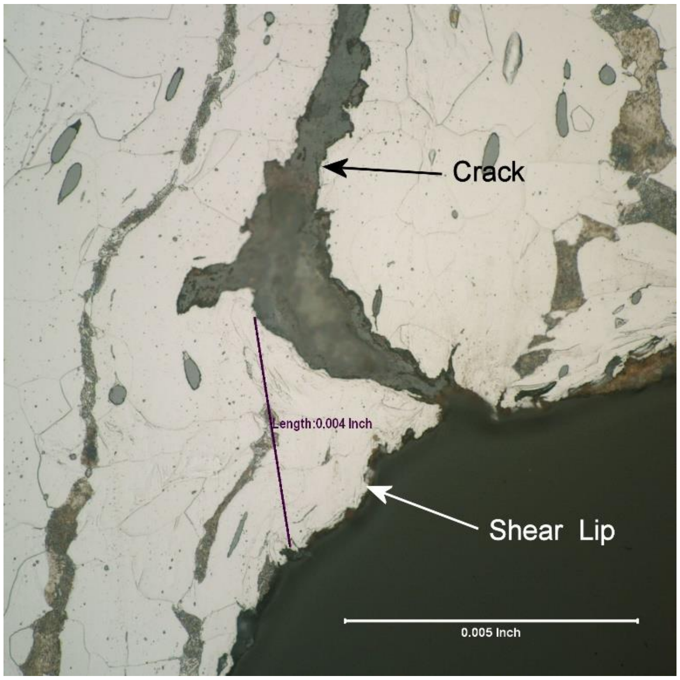

Figure 5 – 400X Fracture Origin 1 for Locking Clamp 1

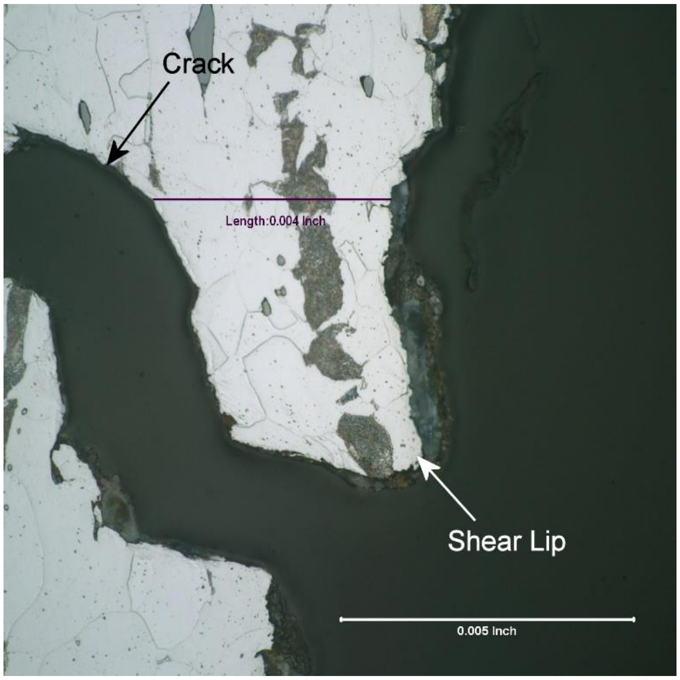

Figure 6 – 400X Fracture Origin 2 for Locking Clamp 1

Figures 5 and 6 show shear lips associated with two of the cracks found in the cross section of Locking Clamp 1. The presence of small shear lips, 0.004 inch in size, was one of the indicators that the material was very brittle. This is a characteristic of 12L14, which is a resulfurized, rephosphorized, and leaded grade of steel. The sulfur, phosphorous, and lead are added to the steel to promote chip breakage which facilitates machining. This reduces the fracture toughness of the steel parallel to the rolling direction to almost zero.

Figure 7 shows the presence of cleavage fracture associated with a surface crack in Locking Clamp 1. Cleavage fracture occurs below the ductile brittle transition temperature of a steel at stress levels below 50% of the steel yield strength. It usually occurs during impact loading. The ductile brittle transition temperature for a resulfurized, rephosphorized, leaded steel can be well above room temperature. The magnitude of the impact load can be very low.

Figure 8 shows both cleavage and intergranular fracture. The intergranular fracture was likely the result of elevated phosphorous in the grain boundaries. Intergranular fracture can occur at very low stress levels, even at static loads, that are well below the materials yield strength.

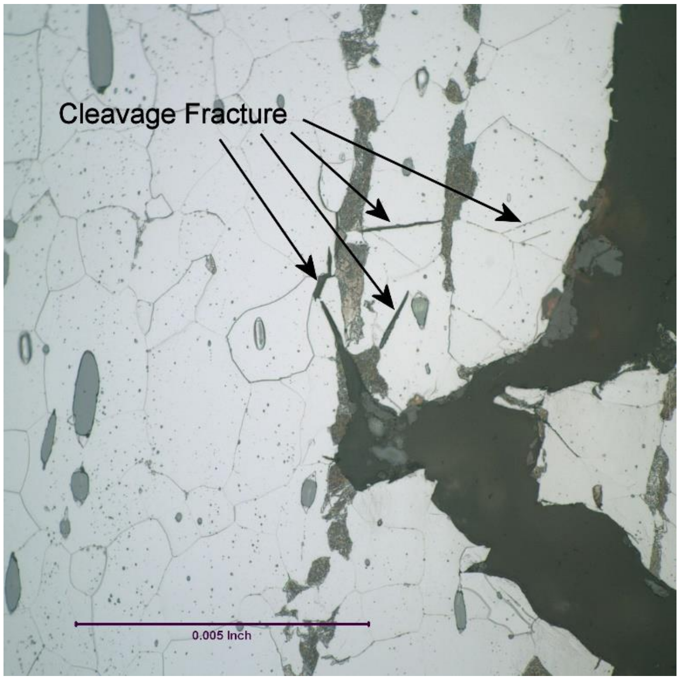

Figure 7 – 400X Cleavage Fracture, Locking Clamp 1

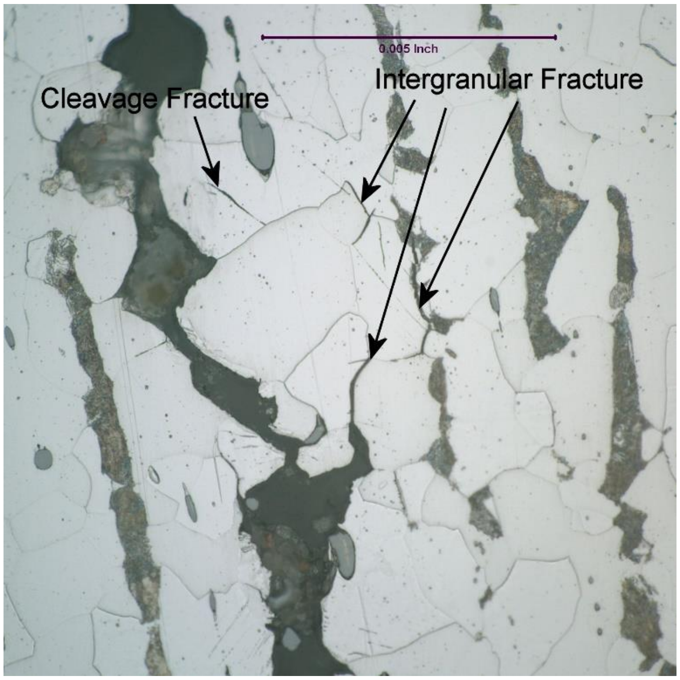

Figure 8 – 400X Cleavage and Intergranular Fracture, Locking Clamp 1

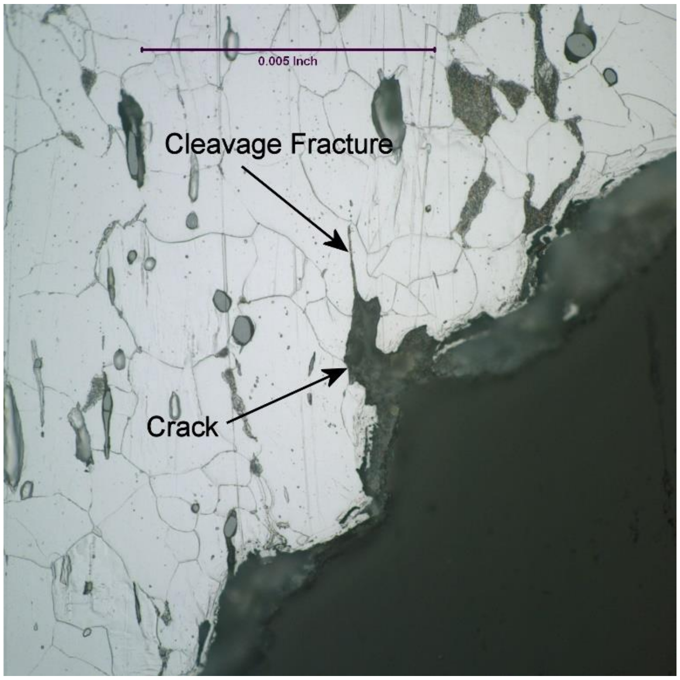

Figure 9 – 400X Crack Initiation Site in Locking Clamp 2

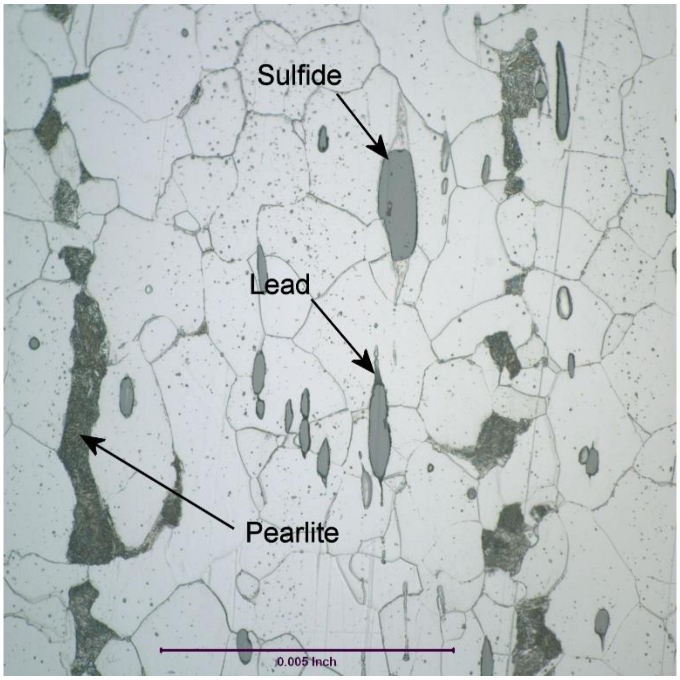

Figure 10 – 400X Alloy Phases of 12L14 in Locking Clamp 2

Figure 9 shows a crack initiation site on the lug surface of Locking Clamp 2. The crack initiation was cleavage fracture.

Figure 10 shows the four visible phases present: ferrite (the light colored, predominant phase), pearlite, gray sulfides, and the dark gray lead, which accumulates at the ends of the sulfide inclusions.

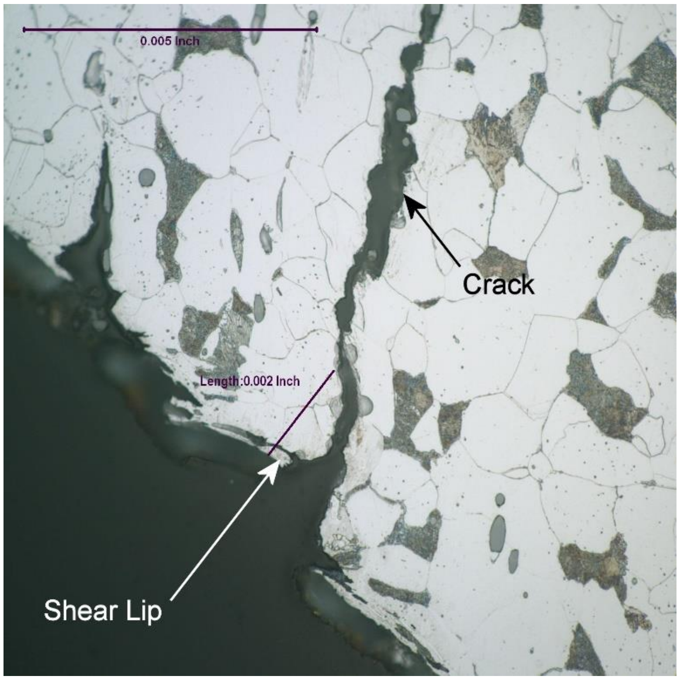

Figure 11 – 400X Shear Lip, Locking Clamp 3

Figure 11 shows the fracture on the lug surface of Locking Clamp 3. The shear lip associated with this crack was very small at 0.002 inch.

Fracture Mechanics

The presence of shear lips meant that it was possible to estimate the Charpy Impact strength of the material, and the load involved in the failure of each locking clamp.

The estimated Charpy Impact strength of Locking Clamp 1 was 0.53 ft-lbs. This is typical for resulfurized steels. Typically, Charpy Impact strengths of less than 15 ft-lbs are considered brittle. The estimated failure stress was 6300 psi., which is less than 10% of the 71,000 psi. normal yield strength of 12L14 steel.

The estimated Charpy Impact strength of Locking Clamp 3 was 0.26 ft-lbs, and the failure stress was 4500 psi.

Free machining steels are not suitable for applications involving impact loading, and/or, high strain rate loading that is applied perpendicular to the rolling direction, or shear stress parallel to the rolling direction.

Discussion

The fabrication of Locking Clamps requires a considerable amount of machining. Free machining steel was chosen to reduce the fabrication cost of the Clamps. Many engineers and designers are unaware of the very poor short transverse properties of free machining steels, and specify them because of cost of manufacturing considerations. This is fine as long as the primary direction of applied force is not perpendicular to rolling direction of the material, as in this case. The locking lugs produced a significant bending moment which resulted in stress perpendicular to rolling direction. These three Locking Clamps had not seen much use, meaning that the machining cost savings were lost due to the short life of the final product.

The life of the Locking Clamps would have been much better if a steel similar to 1018 had been used instead of 12L14. The Locking Clamps would have been virtually indestructible if a mill heat treated low alloy steel such as 4140 had been used.

Over the years, I have seen this mistake made many times. The worst case I ever handled involved a very difficult to machine part where 90% of the annual production was going for warranty replacement parts. Advising a change to a non-free machining steel reduced the annual production quantity by almost 90%, and a reduction in total machining time. This single change gave a very significant cost saving in labor and materials.