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Railway Crane Accident: A Comparative Metallographic Test on Pins Fractured during Operation

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***Abstract*—**Eventually train accidents occur on railways and for some specific cases it is necessary to use a train rescue with a crane positioned under a platform wagon. These tumbled machines are collected and sent to the machine shop or scrap yard. In one of these cranes that were being used to rescue a wagon, occurred a fall of hoist due to fracture of two large pins. The two pins were collected and sent for failure analysis. This work investigates the main cause and the secondary causes for the initiation of the fatigue crack. All standard failure analysis procedures were applied, with careful evaluation of the characteristics of the material, fractured surfaces and, mainly, metallographic tests using an optical microscope to compare the geometry of the peaks and valleys of the thread of the pins and their respective seats. By metallographic analysis, it was concluded that the fatigue cracks were started from a notch (stress concentration) in the valley of the threads of the pin applied to the right side of the crane (pin 1). In this, it was verified that the peaks of the threads of the pin seat did not have proper geometry, with sharp edges being present that caused such notches. The visual analysis showed that fracture of the pin on the left side of the crane (pin 2) was brittle type, being a consequence of the fracture of the first one. Recommendations for this and other railway cranes have been made, such as nondestructive testing, stress calculation, design review, quality control and suitability of the mechanical forming process of the seat threads and pin threads.

***Keywords*—**Crane, fracture, pin, railway.

I. Introduction

IN continental countries, logistics questions related mainly to the transport of high volumes for long distances must be accurately treated. The railway is one of the most efficient and economical transport ways to attend this demand [1].

The railway transport is an efficient transport way mainly if railroads have their integrity preserved during their service lives. Rails catastrophic failures during a train passage, may cause the train derailment, resulting in accidents with human lives and material goods losses [2]-[5].

In order to assist the movement of locomotives and wagons that derailed off the track, a railway crane is used. The objective of this study is to analyze the cause of the fall of the crane hoist caused by the fracture of the two. The consequence of the fracture of these two pins that support the hoist was the fall of the same (accident), see Fig. 1. This crane is used to attended trains accident, being used to move wagons or locomotives that have derailed and are outside the railway track (Fig. 2).

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Fig. 1 The accident occurred with the railway crane due to the fall of the hoist by the fracture of the two support pins

Firstly, visual analysis was performed, followed by laboratory analysis and interpretation of the results, collection of information about the case and inference about the main causes and secondary causes to the failure. This report will detail the activities carried out.

Fatigue failures have one or more crack initiation points, followed by a crack propagation region and a fracture end region (ductile and/or fragile) [6], see Fig. 3.

Discontinuities introduced during the manufacturing process (inclusions, welding irregularities, etc.) or in service (corrosion, impacts, notches, scratches, grooves, etc.) can result in the initiation of fatigue crack from the component surface. In addition, improper design, excessive load or low material resistance can result in fatigue crack initiation. The fractography (fracture analysis as long as well conserved) identifies data to define the mode of fracture and the crack initiation point.

There is a schematic representation of fatigue fractures occurring in a component with a circular cross-section [7], in which the actual fracture can be fitted with one of the existing illustrations (Fig. 4). Also, there is an illustration of cases in which axles were scratched (notched) and consequently fatigue crack initiated and propagated until final collapse (Fig. 5) [6].

The purpose of this work is prepare a failure analysis report based on the two samples sent to the laboratory, defining the main cause(s) and/or secondary cause(s) for the occurrence of the fracture.

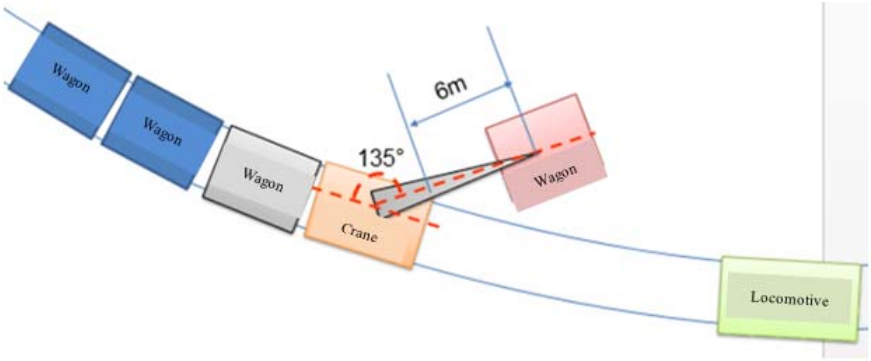

Fig. 2 Schematic diagram of formation of the rescue train during the fracture of the pins and fall of the crane hoist

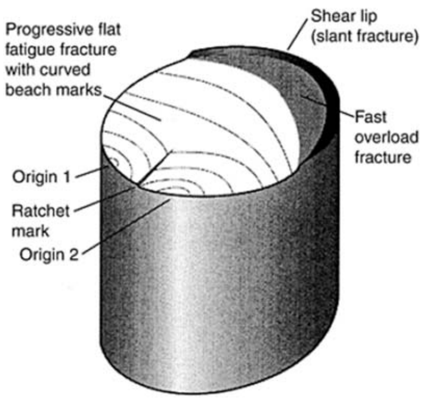

Fig. 3 Fatigue fracture stages: initiation, crack propagation and final collapse [6]

II. Materials and Methods

Standard procedures for failure analysis were applied in this work. The analysis involved the following principal stages: receipt of main information about accident, receipt of components, investigation about material's fabrication and use history, sampling procedures including the preservation of the fractured surface, microfractographic analysis, chemical analysis, metallographic analysis and mechanical tests (hardness).

III. Results and Discussion

The types of analyzes performed and their results will be presented below. Three pins (Fig. 6), with about 400 mm and 50 mm of diameter, were analyzed being called:

- Fractured pin number 1 (right side crane).
- Fractured pin number 2 (left side of crane).
- New pin.

The fractured pin 1 (right side of crane), see Fig. 7, was fractured by fatigue through repeated efforts of unidirectional bending (presence of beach marks). The region of instantaneous and final fracture (about 90% of the cross section) was of the brittle fracture (radial marks).

Further, Fig. 8 shows the detection that the screw peaks of the pin seat have no curvature, that is, they have sharp edges (sharp corners). This figure shows the presence of a sharp corner in the first thread of the screw seat, and the same anomalies in the other threads are also shown.

The fracture of pin 2 was of the brittle bending type through a single overload stress (fracture occurred almost instantaneously). Fig. 9 shows the radial marks proving to be a brittle fracture. The results of the chemical composition showed that the steels of the three pins are similar to those specified for the steel SAE 1045.

TABLE I
Chemistry Analysis

Element	Results: pin 1	Results: pin 2	Results: new pin	Specified SAE 1045
C	0,4756	0,4765	0,5293	0,43 - 0,50
Si	0,2040	0,1748	0,2283	0,15 - 0,35
Mn	0,7880	0,7933	0,7084	0,60 - 0,90
P	0,0182	0,0126	0,0198	máx. 0,04
S	0,0093	0,0182	0,0172	máx. 0,05

The hardness Brinell test (HB) results showed that the values found for the three pins are as expected for the SAE 1045 steel.

TABLE II
Brinell Hardness Test

Sample	HB (187,5 kgf / 2,5 mm)
Pin 1	203
Pin 2	189
New pin	191
Specified SAE 1045	180 - 300

The metallographic examination of all three pins and of the three sites showed is formed by a perlite, as was already expected to be SAE 1045 steel. No irregularities were found in the microstructure. However, the anomaly in the peak of the threads of the seat of the fractured pin 1 was corroborated due to the presence of a cutting edge (Fig. 10). In addition, in the valleys of pin 1 threads several fatigue cracks were found in the beginning of propagation phase (Fig. 11).

The threads of the pin/seat 2 and the pin/new seat were shown with thread geometry to the satisfaction (without cutting edge) and without the presence of cracks and/or plastic deformations. An exception is that only a small crack was found in a valley of the pin 2 thread, most likely as a consequence of the overload imposed after the fracture of pin 1. The comparative table in Fig. 12 shows the comparison between the pin threads and Fig. 13 shows the comparison between the seat threads.

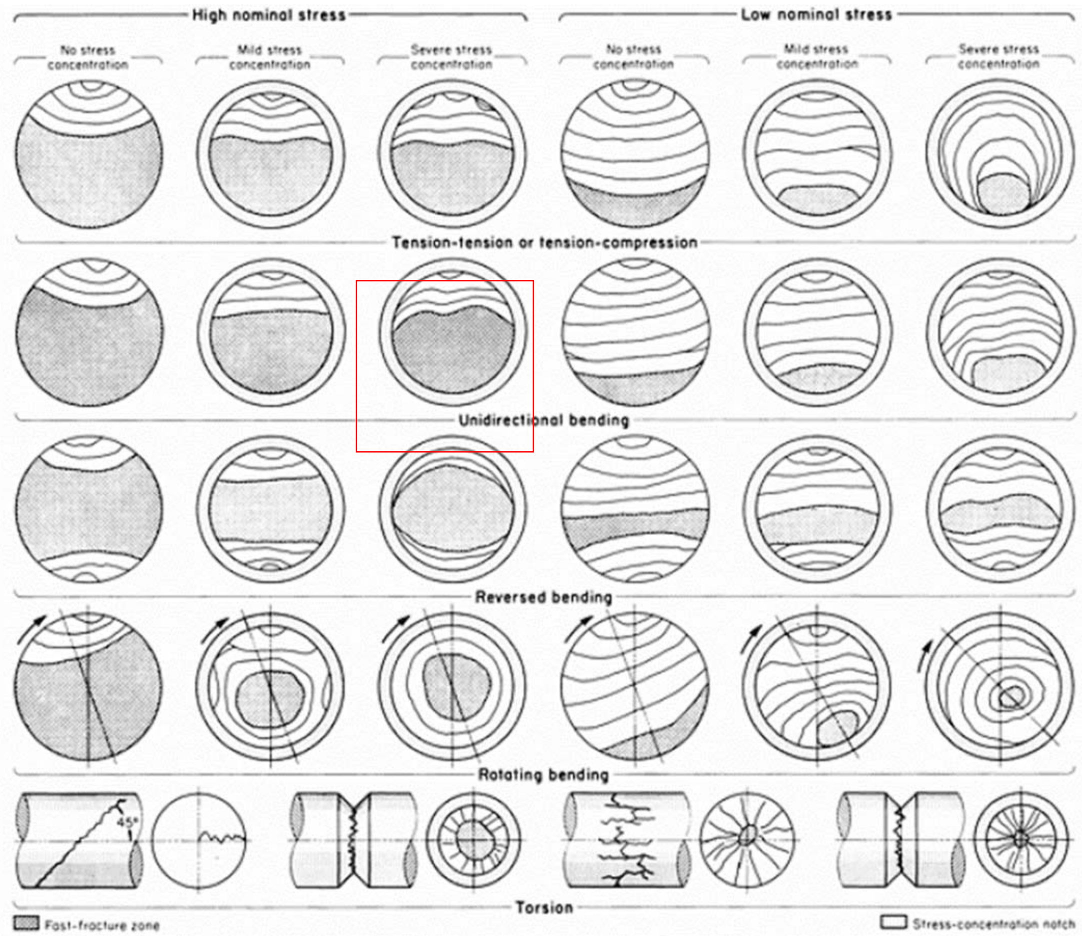

Fig. 4 Schematic diagram to aid in the definition of fatigue fracture type in components with circular cross-section [7]

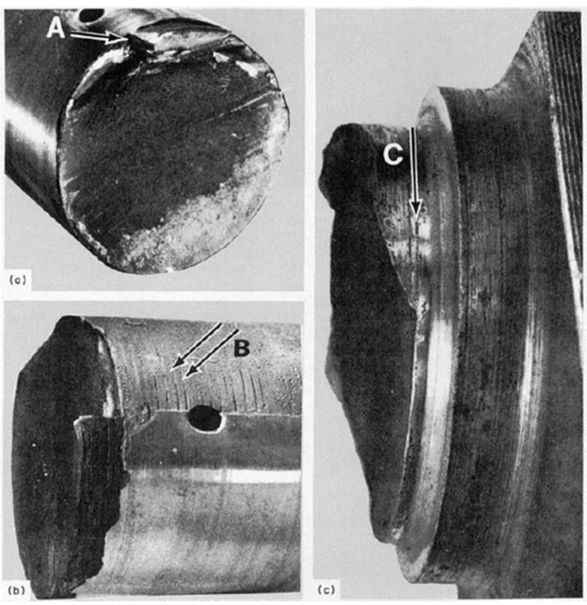

Fig. 5 Presence of scratches/notches/stress concentrators in shaft/pin, being the root cause of the initiation of crack by fatigue [6]

Fig. 6 Samples sent for analysis

Aiming to verify the presence of notches, the fracture of pin 1 was analyzed in SEM (Scanning Electron Microscope). Fig. 14 shows the existence of notch in the valley of the thread of pin 1. This test was also performed for pin 2, with no notch in the thread.

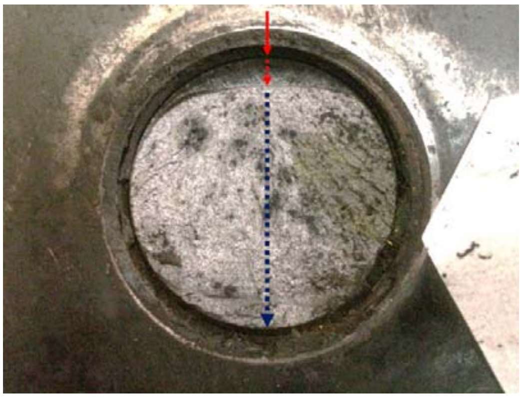

Fig. 7 The visual inspection of the fracture shows: region of beginning of the fatigue crack (red arrow); beach marks: beginning and propagation of fatigue crack by unidirectional flexion (red dotted arrow); and radial marks: region of instantaneous fracture and final of brittle fracture (blue dotted arrow)

In chronological order the steps of the failure`s dynamics in craine hoist pin are listed:

1) Scratching/notching of right side craine (pin 1) during the torque with its seat and/or during operation.
2) Start of the fatigue crack on pin 1.
3) Fatigue crack propagation on pin 1.
4) Final fracture of pin 1.
5) Start of tipping the crane boom to the left.
6) Overload of pin 2 and occurrence of brittle fracture (instantaneous).
7) Total fall of the crane hoist (accident).

Fig. 8 Presence of sharp edge (sharp corners) in the peaks of the threads of the seat of the fracture pin 1

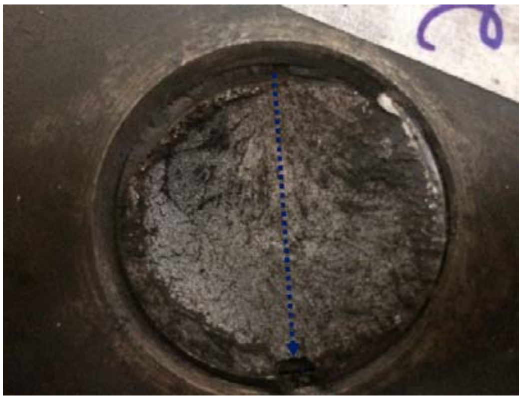

Fig. 9 Fracture of pin 2 due to bending overload stress generating brittle fracture (radial marks). The blue dotted arrow indicates the direction of instantaneous propagation

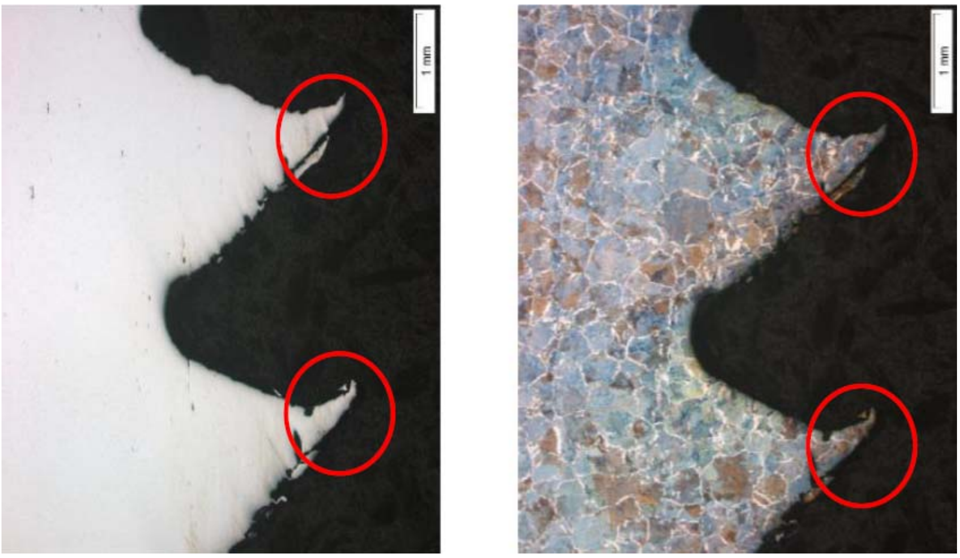

Fig. 10 The presence of a sharp edge in the peaks of the threads of the seat of the fracture pin 1

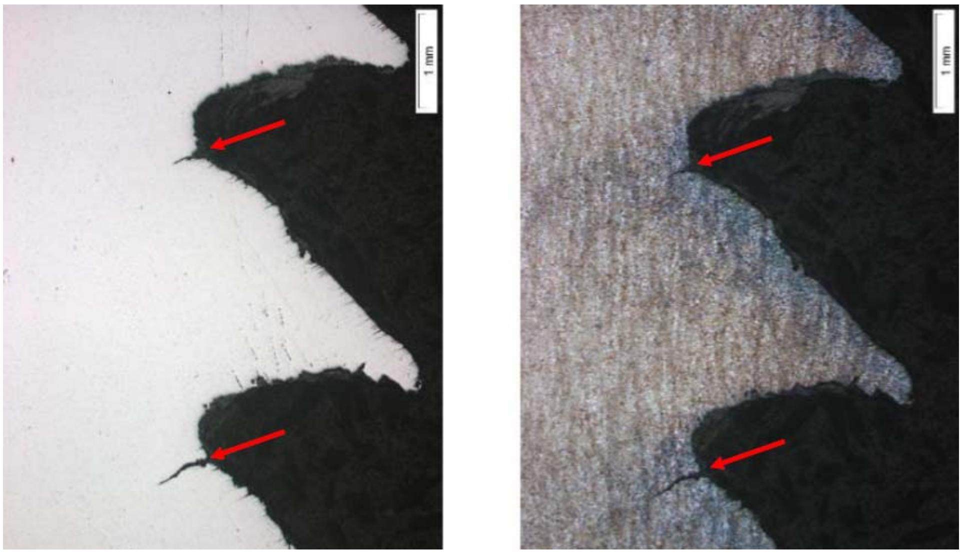

Fig. 11 Recording of several cracks found in some of the valleys of the threads of the fractured pin 1. The threads of pin 1, as well as that of its seat, were probably deformed plastically after the fracture occurred

Fig. 12 Pin threads

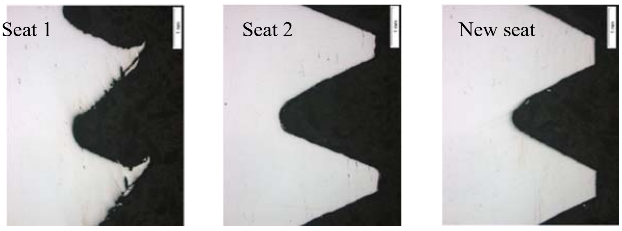

Fig. 13 Seat threads of pins

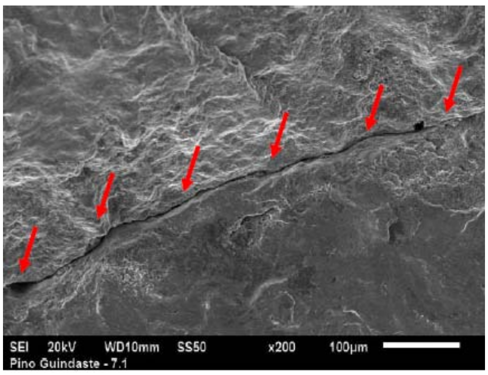

Fig. 14 SEM analysis evidencing the presence of notch (risk) in the valley of the thread of the fractured pine 1

The schematic drawing highlighted by the red square in Fig. 4 presented in the literature review is similar to the fracture of pin 1. This figure shows that there is a severe stress concentrator, unidirectional bending and high nominal stress.

The visual and laboratory results showed the presence of a severe notch in pin 1 (which caused the failure), which is equivalent to that stated in the literature review.

IV. Conclusions and Recommendations

The main cause of the failure was the notch caused in valley of pin 1 (right side of crane hoist) by the action/contact with the cutting edge contain in the peaks of the seat threads. From these grooves, the fatigue crack was started in pin 1.

Other secondary causes are not discarded, such as load overload, under dimensioning of the project, among others.

Recommendations:

- Perform visual tests with magnifying glass and/or non-destructive tests (dye penetrant, ultrasonic, etc.) on all the pins applied on the crane in order to detect notches and/or crack initiation.
- Calculate efforts to determine whether SAE 1045 steel (with or without heat treatment) and/or the entire crane is sufficient for the mechanical stresses imposed by the operation. Same for the seat.
- Elaborate technical drawing of the pin and seat, as well as elaborate technical specification containing various details including the design, material and type of heat treatment.
- Adapt the mechanical forming process of the seat and/or pin threads in order to eliminate sharp edges on the thread peaks.

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