COMPRESSION PRESS BOLTS FAILURE ANALYSIS

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Abstract: *This paper is focused on bolts failure analysis of a compression press. 8 bolts were used to attach the high speed cylinder cap to the upper ram cylinder of a hydraulic press used to produce forging parts. The bolts had been in service less than one year. Six (6) broken bolts out of eight (8) were submitted for failure analysis. One of the most common failure mechanism for bolts is fatigue. Fatigue cracks initiate and propagate in regions where the strain is most severe. Most fatigue cracks initiate and grow from structural defects. The manner through which the crack propagates through the material gives great insight into the mode of fracture.*

Incorrect placement of a component or incorrect assembly order can cause high residual stresses or failure to occur. Improper specifications or torque requirements can also cause premature bolts failure.

Keywords: compression, fatigue, hardness

1. INTRODUCTION

Welded and bolted connections can be used in steel structures. Bolted connections are commonly used because of the ease of fabrication, buildability and ability to accommodate minor site adjustments.

The different types of bolted connections include cover plates, end plates and cleats, and in each of these connections the bolts are used to mechanically fasten the steel elements [1].

In many cases bolted joints are the weakest elements in structures or mechanisms, so they are the key elements when they are subjected to an increasing monotonic load until fracture or in presence of cyclic loads (fatigue).

Bolts generally fail due to: overstress, fatigue, corrosion, wear and erosion, and hydrogen embrittlement. The location of failure gives us some clues about the type of failure. Fatigue is the phenomenon that occurs in bolt materials as a result of cyclic variations of the applied stress [2, 3, 4]. Beach marks and striations, typical of fatigue fractures, are present on all of the fracture surfaces. Fatigue failure of threaded fasteners is most often associated with insufficient tightening of the fastener, resulting in flexing and subsequent fracture [5, 6, 7, 8].

The fatigue fracture of bolts typically has some characteristic features: ratchet marks at the initiation location, a relatively smooth surface and distinct crack propagation patterns of clam shells or beach marks on the surface [3, 9, 10, 11, 12, 13].

2. RESULTS

Working Conditions

Six (6) broken bolts out of eight (8) were submitted for failure analysis. All 8 bolts were used to attach the high speed cylinder cap to the upper ram cylinder of a hydraulic press used to produce forging parts. The bolts had been in service less than one year. All analyzed bolts failed due to mechanical fatigue except one which failed from an overload. They were reported to be type MFL 10.9. The grade 10.9 is used for bolted connections subject to fatigue, because of its high fatigue strength and limited deformation characteristics.

Typical mechanical properties are: stress area 245mm^2, proof stress 830N/mm^2; proof load 203.4 KN; tensile stress 1040N/mm^2; torque 546N-m; hardness 32-39HRC; elongation 9.0%.

The stress variation was between a maximum stress and a minimum stress that means that the stress ratio R is a positive number less than 1**.**

Failure Analysis-Macroscopic examination

Fracture surface examination and metallographic analysis were used to determine the cause of failure. The macroscopic examination can reveal a wealth of information on the location of fracture origins, direction of cracking, configuration of the stress state, and the last region to fail (shear lip) [10]. The bolts used for investigation were cleaned up with alcohol using an ultrasonic cleaning machine. They were examined visually and with stereoscope at magnifications of 6.7 to 45X. The bolted assembly has contained 8 bolts but only 6 of them were recovered and submitted for examination. The position of each bolt was unknown. Each bolt was marked with a number starting with 1 to 6. All bolts present typical fatigue failure aspects (Fig.1), except bolt # 5 which presents ductile fracture.

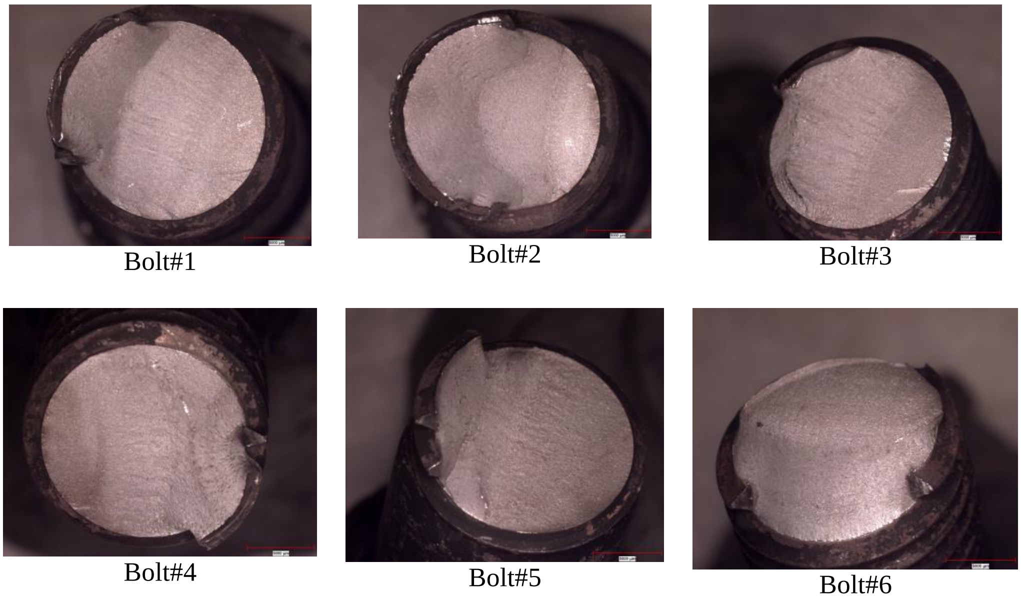


Figure 1 *Macroscopic aspects of fracture surfaces, 6.7X*

The Table 1 presents the calculated surface of fatigue fracture area and the position of fracture initiation for each bolt. There is no bolt to present fracture at the head/shank radius.

Table 1 *Calculated surface of fatigue fracture area and position of fracture initiation*

Bolt #	Fatigue fracture surface, %	Position of fracture initiation (thread #)	Bolt #	Fatigue fracture surface, %	Position of fracture initiation (thread #)
1	51.5	5	4	17.00	5
2	41.70	5	5	11.50	1
3	22.8	5	6	54.00	5

Before failure to occur we did not have the opportunity to observe the position of each bolt in relation with other bolts on the bolted assembly. Therefore we cannot specify exactly on which side of assembly the nucleation of fatigue cracks occurred first, which bolt failed first or in which order they failed.

It has been noticed the presence of a shiny line at the contact between the bolt and the press flanges, at the fillet radius between head and shank of the bolts. It looks like this was the only contact between bolts and the press flanges, which make us to draw the conclusion that the fillet radius of the press flange was not appropriate or maybe the torque was inadequate. Incorrect placement of a component or incorrect assembly order can also cause high residual stresses or failure to occur. Improper specifications or torque requirements can also cause premature failure. Misalignment of components within the assembly could also result in inadequate service life, because the stresses are not what the designer had anticipated.

Failure Analysis-Microscopic examination

J Toribio and others [14] have analyzed the tensile fatigue behavior of bolted joints constituted by commercial steel bolts. They studied the surfaces of fatigue fracture. According to them, fatigue fracture occurs on the first thread's rod inside the bolted joint where the surface tension is the highest. The fracture surface first shows a fatigued region, then a zone with plane fracture and finally an inclined fracture or shear lip.

Failures at the first engaged thread, which has the highest concentration of stress, are virtually always the result of fatigue. Fatigue fracture normally result from cyclic stresses that are well below the static yield strength of material. Fatigue cracks initiate and propagate in regions where the strain is most severe. Most fatigue cracks initiate and grow from structural defects.

The studied bolts, we are thinking that, initially all of them were in good state, which means the load was uniform distributed to all 8 bolts of joint assembly. So, the load amount per bolt was equal and in the specification limits.

Once the crack occurred, the crack itself develops in an area with higher stress concentration (stress intensification factor), and it continues to propagate progressively with each application of the load until the remaining stressed area finally becomes so small that it cannot support statically the load and an unexpected fracture outcomes. The fatigue portion begins at the point of high-stress concentration and it spreads outward showing concentric rings as it advances with repeated load. The final fracture surface has the same appearance as that of a ductile tensile specimen with a deep groove.

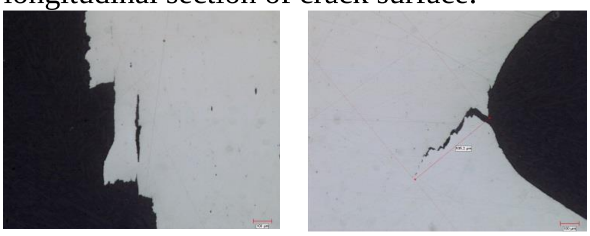
Probably the root of first loaded flank of bolt 6 has presented a material nonconformity – material overstretched after could forming, or the bolt was incorrect pre-loaded, so a fatigue crack was initiated and then it has started to propagate.

The crack of bolt 6 has been propagated all-around of the root of thread for more than 360º so the crack appeared also on second loaded thread, which explains the presence of a step on fatigue fracture surface and why the thread is separated from the body.

Once in the bolt 6 the crack started to propagate the section became smaller and smaller and the nominal load on each other bolt has increased. Another cause of load increase could be that the press was used for parts requiring a higher load. These likely changes created the conditions for crack initiation and propagation on bolt 1. These two bolts 6 and 1 have had the largest fatigue surfaces: ~51%.

So, fatigue cracks have been propagated on bolts 6 and 1 and consequently the load was uniform distributed to the rest of the bolts and therefore an increase of the nominal stress in each of them took place with a reduction of fatigue fracture surface.

Figure 2 presents microstructures on longitudinal section of crack surface:



a) B5, Core crack aspect, 50X   b) B5, Crack at root, 50X

Figure 2 *Aspect of crack and the place where the picture was taken in bolt#5*

Nondestructive evaluation (NDE) is a good way for cracks examination, without causing permanent damages to the components. There are several NDE's methods that are available: radiography, ultrasonic, dye penetrate, magnetic particle or Eddy current. We used magnetic particle inspection (MPI) which showed some slightly indications at the root of threads but no cracks were found on sectioned samples.

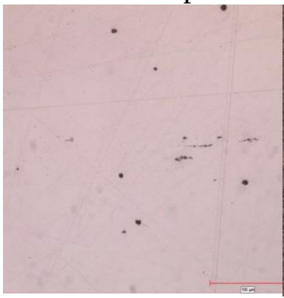


Figure 3 *Non-metallic inclusions on longitudinal section of bolt #1, 200X*

Figure 4. *Etched microstructure of bolt #7 on the core, 200X*

Metallographic longitudinal sections through the fatigue fracture origin were prepared for examination. Etched and un-etched microstructures were studied (Fig. 3 and Fig. 4), but no differences were noticed. Etched microstructure of unused bolt (#7, new bolt) on the core is showed in Fig. 4. No significant flaws were seen under the microscope in the regions of crack initiation. This indicates that the fatigue crack initiation was due mainly to stress factors.

Chemical analysis

Two different bolts were tested for carbon content by using C-200 LECO Carbon analyzer. The bolt chemical composition is presented in table below:

Table 2 *Bolt chemical composition*

C	Mn	Si	Cr	P
0.4216	1.5052	0.1979	0.1597	0.0146
S	**Al**	**Ti**	**B**	
0.0037	0.0979	0.0269	0.0021	

Correlating the results for microstructure, hardness and carbon content the producer used an alloy steel quenched and tempered.
Material hardness (HRC) was tested (Fig. 5) on cross section mounted and polished sample. The average of obtained results was found to be 38.63.

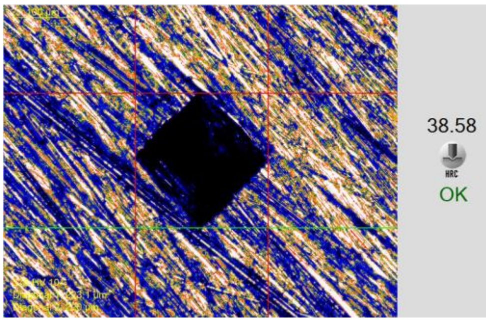


Figure 5 *Hardness indentation*

3. DISCUTIONS

Fatigue is the major cause of the failure (about 85% of bolts failures). Most of these failures occur in “tension-tension” applications where the bolts are subjected to a small preload and an alternating service load.

Crack initiation and propagation are essential to fracture. The manner through which the crack propagates through the material gives great insight into the mode of fracture.

Processing [17] can have a large influence on properties and the resulting residual stresses. Cold forming, such as stretching or deep drawing, can develop highly localized residual stresses.

The assembly of a group of components can also cause eventual failure. Incorrect placement of a component or incorrect assembly order can also cause high residual stresses or failure to occur. Improper specifications or torque requirements can also cause premature failure. Misalignment of components within the assembly could also result in inadequate service life, because the stresses are not what the designer had anticipated.

The presence of a shiny line at the contact between the bolt and the press flanges, at the fillet radius between head and shank of the bolts, make us to draw the conclusion that the fillet radius of the press flange was not appropriate or maybe the torque was inadequate. It can be a consequence of an inadequate design or inadequate maintenance.

Fatigue failure of threaded fasteners is most often associated with insufficient tightening of the fastener, resulting in flexing and subsequent fracture. Each bolt needs to be torqued as close to the yield point without exceeding it will maximize the service life of fastener assemblies.

Recent tests in France have indicated that considerable reductions in bolt pre-load of 25% to 45% can occur over a 2 to 3 month period when standard protective paint coatings are used [15].

In order to maximize fatigue lifetime, it is crucial to fabricate the threads by cold rolling following heat treatment.

4. CONCLUSION

Fatigue failures of bolts and fasteners can be avoided through good design practices, proper installation and routine inspection practices:

-the bolts were subjected to a combination between offset and random fatigue stress cycles;

-last bolt failed by overload;

-thread is slightly decarburized at the tip;

-the bolts present nonmetallic inclusions on microstructure;

-new installed bolts should be marked in order to know the initial position and to monitor the situation if they rotate because of vibrations from press running;

-the torque should be checked from time to time to observe if the relaxation occurred;

-use of proper selected and installed washers;

-bolts should be specifically selected to be obtained by rolling applied after heat treatment;

-the geometry of flange (fillet radius) at the contact with the bolts should be changed accordingly.

ACKNOWLEDGMENTS

The authors acknowledge financial support from the project “Integrated Center for research, development and innovation in Advanced Materials, Nanotechnologies, and Distributed Systems for fabrication and control”, Contract No. 671/09.04.2015, Sectoral Operational Program for Increase of the Economic Competitiveness co-funded from the European Regional Development Fund.

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