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Analysis of Bolt Failure Locations for Predictive Maintenance

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Abstract

In this work, a population of fractured joint bolts have been collected from automotive and tire plants, and an analysis of each bolt is performed to determine the cause of failure, and crack initiation site location on the bolt. The bolts are then grouped by failure cause and location to investigate the probability of failures and probability of failure location. The results show that low-cycle and high-cycle fatigue account for 70% of bolt failures, and that 80% of bolt failures occur deep in the threaded region in the bolt. Failure locations that were closer to the intersection of the head and the shank were only found in samples that were determined to have failed due to low-cycle fatigue. Still then, only 40% of bolt failures that result from low cycle fatigue take place closer to the head, and 60% of the failures occur in the threaded region away from the head. The results of this study can help predict the failure location on the bolt, and thus help guide preventive maintenance procedures on joint bolts.

Keywords
Bolt Failure, Low-Cycle Fatigue, High-Cycle Fatigue

1. Introduction
Bolt failure has been the attributed cause of many accidents and catastrophic failures that were documented in literature, such as the break in the water main supply of Boston area in 2010 (Pantić, Ballinger, & Bambei, 2011) which resulted in a state of emergency in the State of Massachusetts, the crash of a light sport airplane in Helena, MT in 2014 due to bolt overloads (National Transportation Safety Board, 2015), the collapse of the 390-feet wind turbine near Vetlanda, Sweden in 2018, after fatigue caused bolt failures in the lower flange joint (Swedish Accident

Investigation Authority, 2017) (Figure 1), and the collapse of the roof of the Kemper Arena in Kansas City in 1979 which is attributed to fatigue stresses in bolts (Levy & Salvadori, 2002).

Although many works are available in literature that investigate causes of failure in fasteners, most of these research efforts are performed on isolated cases of bolt failures (Hudgins, James, & FASM, 2014) (Gray, 1998) (Unbrako, 2001) (Hui-li & Si-feng, 2014), or on mathematical models that are verified by simulated bolted joints (Kim, Yoon, & Kang, 2007). It is commonly known that a good percentage of fatigue failures occur at the intersection of the shank and the head of the fastener, and at the bolt engagement with the nut (Tantawi & Tantawi, Bolt failure due to low-cycle fatigue, 2015) (Tantawi, Ali, & Tantawi, 2015). However, there is barely any scientific study in literature that quantifies the probability of failure locations on bolts. This is mainly due to the difficulty in collecting a large population of fractured bolts. Furthermore, most knowledge of bolt failures comes from construction and structural failures, and rarely from the manufacturing industry, mainly due to the difficulty for researchers and academic institutions to get access to failed equipment in industrial plants, rendering collaborative research efforts difficult to achieve.

Figure 1. A wind turbine structure that collapsed due to a bolt failure (Swedish Accident Investigation Authority, 2017), picture is obtained with permission from Vestas Wind Systems A/S, Sweden (Left). Bolted bridge structure in Ohio (Center). Bolts at the base of the pier W-6 tower of the San Francisco Bay Bridge (Right). (Center and Right pictures are in the public domain, source: Wikimedia Commons).

Bolt failure may be caused by overloads, corrosion cracking, creep, embrittlement, and fatigue (Hudgins, James, & FASM, 2014). In this research, investigation of the causes of fastener failures is performed on a population of fractured bolts from the automotive and tire industries, then a statistical analysis is performed based on the results to determine the most probable locations on fasteners where fatigue failures will occur. It is commonly known that a large percentage of bolt failures occurs at the intersection of the shank and the head of the fastener, but no scientific research is available that quantifies that with a confidence level based on a population of fractured bolts. Most available data come from construction and structural failures due to the rigorous procedures that industrial plants follow to give educational institutions access to their failed equipment, rendering collaborative research efforts difficult to achieve. This is in addition to the difficulty in collecting a large population of fractured bolts.

In this study, an investigation of the modes of failure in bolts is performed on a population of fractured bolts that has been collected from automotive and tire plants across the United States. Statistical analysis will then be performed on the results of this investigation to predict the probability of failure at different locations on the bolts.

1.1 Objectives

The main objective of this research is to quantify the causes of bolt failures in industrial settings, and to use statistical data to quantify the locations on bolts and failure modes that cause failure from an independent perspective.

3. Methods

Fractured bolts and fasteners have been collected from the tire and auto industries (Figures 2 and 3) mainly in the Middle Tennessee region. Bridgestone, which has two nearby plants as well as its North America headquarters, and the Nissan Smyrna automotive plant, which is one of the largest automotive manufacturing plants in the United States.

Bolt Failure Modes

a. **Bolt failure due to fatigue stress:** Principles of fracture mechanics as outlined in the British Standard Guide BS 7910 (British Standard Technical Committee WEE/37, 2007) are used for this analysis. The fatigue stresses that cause this type of failure do not have to exceed the ultimate strength of the material, but occur repeatedly resulting in a crack propagation, and ultimately failure. Most fastener failures in industry are caused by fatigue (Unbrako, 2001). Fatigue failures may be of the low cycle fatigue (LCF) type or the high cycle fatigue (HCF) type (Hou, Wicks, & Antoniou, 2002). Research has shown that rolled threads exhibit higher fatigue life than machined threads, also threads rolled after heat treatment show better fatigue performance than those rolled before heat treatment (Naval Surface Warfare Center Carderock Division, 2010). Probability of fatigue failure increases if the initial pre-load torque is too low (Wagle & Kato, 2009). Other factors that contribute to increasing the probability of fatigue failure include a low material yield stress, relaxation due to temperature increases, bolt loosening due to vibration, and exceeding endurance limits of the bolt.

   The range of stresses that caused the bolt fatigue propagation can be calculated using the fracture mechanics method detailed in the British Standard Guide BS 7910. In this method, crack propagation takes place according to the relationship between crack growth rate d*a*/d*N* (in units of mm/cycle) and the range of stress intensity factor ΔK (in units of $N/mm^{3/2}$). The relationship between the two quantities is sigmoidal when they are plotted in a logarithmic scale, but can be approximated as a linear relationship in the central portion, in which case it is referred to as the Paris Law (PARIS & ERDOGAN, 1963) (Barsom, 1971):

$$\frac{da}{dN} = A(\Delta K)^m \qquad \textbf{\textit{Equation 1}}$$

   Where:
   $A = 5.21 \times 10^{-13}$ for steels operating in air and below 100 ^{o}C
   $m = 3$ for steels operating in air and below 100 ^{o}C
   The crack growth rate d*a*/d*N* is found from the distances between the fatigue ridges which in turn can be calculated from the optical and SEM images of the fractured surface. Knowing that, the range of stress intensity factor ΔK is found from ***Equation 1***. Finally, the stress intensity factor range ΔK is a function of the structural geometry factor *Y*, the stress range $\Delta\sigma$, and the instantaneous crack size *a* as follows:

$$\Delta K = Y(\Delta\sigma)\sqrt{\pi a} \qquad \textbf{\textit{Equation 2}}$$

b. **Bolt failure due to stress corrosion cracking:** These are the failures that result from corrosive environment in the workplace coupled with stress (Gray, 1998) (Lee, Choi, Lee, & Kim, 2007). Corrosion cracking is a known problem in sea vessels and in population centers along coast lines where NaCl is present, as well as the industrial environments that commonly contain SO_2 (Hui-li & Si-feng, 2014). The stress-corrosion failure life of a bolt may be divided into the crack growth life and the crack propagation life (Hui-li & Si-feng, 2014).

c. **Bolt failure due to fracture from tensile stresses:** This failure is caused by creep and overloads that result in stresses that exceed the ultimate strength of the material. This failure typically occurs at the bolt if the proper number of threads are engaged (Brown, Morrow, Durbin, & Baca, 2008) (Oberg, Jones, Holbrook, & Ryffel, 2008), otherwise, thread stripping takes place before bolt fracture, a scenario that should be avoided. Sandia National Labs Guideline for bolted joints (Brown, Morrow, Durbin, & Baca, 2008) recommends the use of bolts with threads of a lower tensile strength than that of the threads of the bolted material. Furthermore, bolt fracture from axial overloads should occur in the body or the threads rather than at the intersection of the head and the shank (Robinson, 2006). A sample of a bolt that failed from pure tensile overloads is shown in Figure 2. Here the bolt underwent thinning in its middle section.

Figure 2. A bolt that failed from pure tensile overloads. The bolt underwent thinning and axial elongation, and was retrieved by the technicians before it fractured.

d. **Bolt failure due to shear overloads:** this failure results from either a torsional or an impact loading. Commonly due to an operator error such as bolt misalignment during installation, twisting, or using the bolt to support heavy loads.

4. Data Collection

In the first stage of the investigation, hardness tests are performed on bolt samples that are manufactured outside the United States to verify bolt grades and to detect any surface decarburization. This verification step is done to avoid any problems similar to that which occurred in the 1980’s and early 1990’s, in which counterfeit bolts of foreign origin found their way in major manufacturer plants in the United States (Robinson, 2006).

Afterwards, five bolt failure modes are investigated by microstructural characterization using optical microscopy, a Keyence BZ-X800 Fluorescence Microscope was used for the analysis. Other methods may be used such as thermal analysis (Mohammadizadeh, et al., 2020) or using transmission electron and scanning electron microscope imaging (Molaei, Alizadeh, Attarian, & Jaferian, 2015) (Tantawi, Waddell, & Williams, Structural and composition analysis of Apex™ and Foturan™ photodefinable glasses, 2013) (Tantawi, Oates, Kamali-Sarvestani, Bergquist, & Williams, 2010), or Atomic Force Microscopy, which has the ability to capture both nanomorphology and mechanical stresses (Tantawi, Berdiev, Cerro, & Williams, 2013). However optical imaging provides the fastest approach while capturing real images of the structure (Figure 3).

Figure 3. Failed bolts that have been collected for the study

5. Results and Discussion

One of the failed bolts is shown in Figure 4. Four of the failed bolt population, had a 10 mm diameter Holo-Krome socket head cap screws failed in a stamping press machine in an automotive plant (Figure 5). The screws were manufactured in the United States, and made of alloy steel with a black oxide finish and a grade class of 12.9. Each of the failed screws was subjected to tensile and shear stresses during the cyclic operation of the steel pressing machine. Figure 4 shows the fracture at one of the screws. it can be seen that the screw failure location is at the vicinity of the stress concentration at intersection of the head and shank, a common site for fatigue crack initiation.

Investigation of the cross section of the fractured screw suggests that the cause of failure is initiated by a single fatigue crack propagation, followed by a tensile overload that caused rupture. The area of the overload rupture region formed approximately 75% of the cross-sectional area (characterized by the rough surface). This indicates that the bolt was subjected to high stress low-cycle fatigue. Consequently, from this analysis, the screw was most possibly subjected to heavy shock loads, that caused a fatigue crack to initiate at the root of the second thread from the head, the high tensile shock stresses caused the bolt to fail shortly after a fatigue crack was initiated.

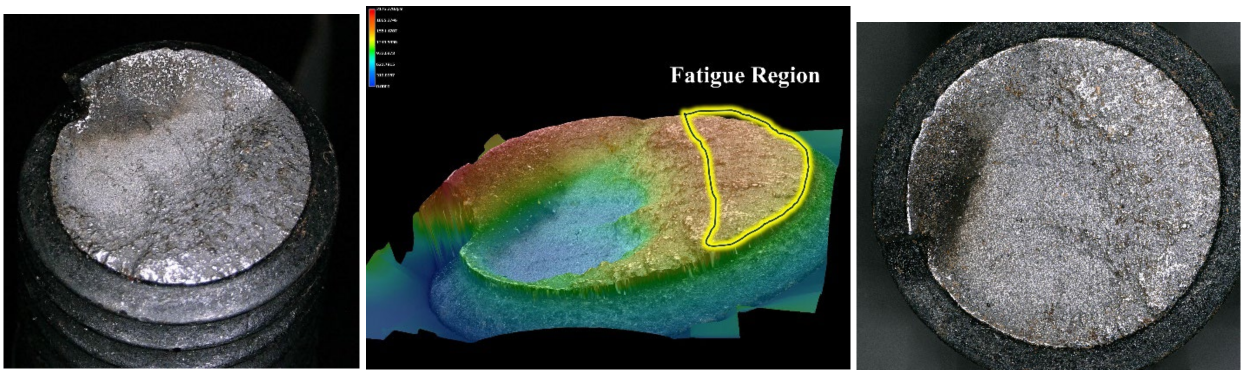

Figure 4. A view of a failed screw at the failure location (Left), a topograph image that shows the depths of the fractured surface and the fatigue and overload failure regions (Center), and the cross section of the failed surface (Right).

All the screws that came from the same stamping press machine exhibited similar failures with single crack initiation sites that usually occurred at the root diameter but at different locations along the shank. Another sample failure that was very similar to the one shown previously is shown in figure. Some bolts from the machine also suffered from minor thread stripping on the first four threads on the threaded part of the failed screw, another indication of the high tensile stresses in the axial direction. It should also be mentioned that the stripping might also have occurred when the operating technician tried to pull the ruptured screws out from its location.

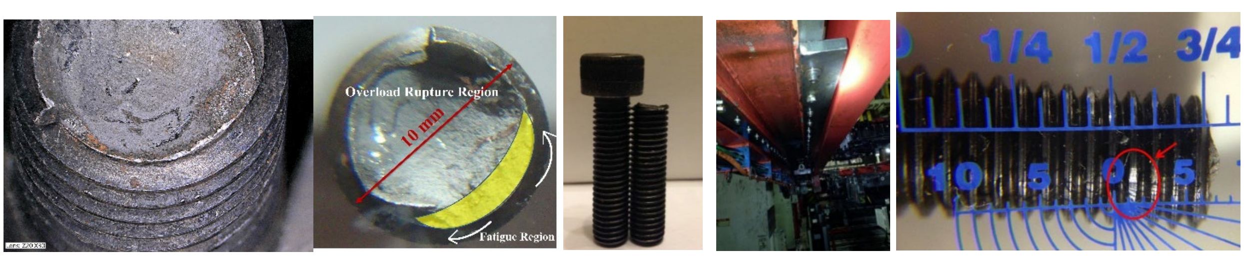

Figure 5. A failed screw sample that exhibited similar fail pattern to that in Figure 4. The sample is shown next to a new socket head cap screw (Center). The stamping press from which the fractured bolt was taken (Center-Right), thread stripping on the sample (Right) (Tantawi, Ali, & Tantawi, 2015).

From Figure 5, it can be noticed that a fatigue crack initiated at the second thread root from the head of the screw in one location on the root diameter that could have resulted from a bending stress. The crack then propagated in both directions along the circumference of the screw. When the fatigue crack formed a crescent-shape that was 1.7 mm wide at the center, the increase in the tensile stresses due to the reduced operating area caused bolt rupture due to overload. The area of the overload rupture region formed approximately 85% of the cross-sectional area (characterized by the rough surface). This indicates that the bolt was subjected to high stress low-cycle fatigue. Consequently, from this analysis, the screw was most possibly subjected to heavy shock loads, that caused a fatigue crack to initiate at the root of the second thread from the head, the high tensile shock stresses caused the bolt to fail shortly after a fatigue crack was initiated.

Preliminary investigation was conducted on eight other bolts; in total, seven bolts out of the population showed signs of a fatigue failure. Figure 5 shows a bolt that failed from a high-cycle fatigue (Figure 6- Right), and what appears to be a failure from a combination of a shear and tensile overload (Figure 6- Left).

Figure 6**.** Failure due to a combination of shear and tensile overloads (Left), and due to high-cycle fatigue (Right).

5.1 Numerical Results

A total of ten fasteners were collected, and for each of the bolts in the bolt population, cause of failure is determined, and crack initiation site is located on each bolt that failed from fatigue. Table 1 below shows the population grouped by cause of failure and location on the bolt.

Table 1. Bolt population grouped by failure cause and location

Cause of Failure in the fastener	Number of Fasteners	Location on Fastener
Low Cycle Fatigue	5	Intersection of head and shank (2) Threaded region away from head (3)
High Cycle Fatigue	2	Threaded region
Axial overload	1	Threaded region
Shear Overload	2	Threaded region: Away from head (1), Close to head (1)

From Table 1 above, it can be seen that low-cycle and high-cycle fatigue account for 70% of bolt failures. This result was expected, since fatigue is known to be the main cause of failure in mechanical structures and materials. The results also show that 80% of bolt failures occur deep in the threaded region in the bolt.

Failure locations that were closer to the intersection of the head and the shank were only found in samples that were determined to have failed due to low-cycle fatigue. Still then, only 40% of bolt failures that result from low cycle fatigue take place closer to the head, and 60% of the failures occur in the threaded region away from the head.

These results can aid in standardizing predictive maintenance on fasteners on equipment in manufacturing plants. By knowing that 80% of failures occur at the threaded region away from the head of the fastener, inspection of the bolt head alone will likely not be effective.

With the advances of the fourth industrial revolution referred to as Industry 4.0 (Tantawi K. , Fidan, Musa, & Tantawy, 2023) (Tantawi, Sokolov, & Tantawi, Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0

Collaboration, 2019), machine condition monitoring can predict failures by monitoring the vibrations and assessing severity and operating conditions (Tantawi, Fidan, & Tantawy, 2019) (Dinardo, Fabbiano, & Vacca, 2018), or using AI-based vision systems to detect mechanical fasteners and improve energy efficiency (Terry, et al., 2020) (Karthikeyan & Subashini, 2021). By knowing the most predictable locations on fasteners, and by assessing the changes in vibrations, a smart machine can predict a possible fastener failure before it occurs. In future work, the relationship between flexibility in bolted joints and the statistics of failures will be investigated using simple dynamic models (Alazard, Cumer, & Tantawi, 2008) (Tantawi, Alazard, & Cumer, 2008), bolted joints are known to exhibit higher flexibility than other types of joints such as welded joints (Cabaleiro, Moutinho, González-Gaya, Caetano, & Rosales-Prieto, 2021).

6. Conclusion

A population of ten fractured bolts were collected from manufacturing industrial settings, and investigated to determine the failure cause in each fastener. Low-Cycle and High-cycle fatigue accounted for 70% of the bolt failures. The vast majority of all failures (80%) take place at the threaded region away from the head of the bolt. Only failures due to low-cycle fatigue were found to occur closer to the head.

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References

Alazard, D., Cumer, C., & Tantawi, K. Linear dynamic modeling of spacecraft with various flexible appendages and on-board angular momentums. *7th ESA Guidance, Navigation and Control Conference.* Tralee, Ireland, 2008

Barsom, J. M. Fatigue-crack propagation in steels of various yield strengths. *J. Eng. Ind, vol. 93*(4), 1190-1196, 1971

British Standard Technical Committee WEE/37. *British Standard Guide to Methods for Assessing the Acceptability of Flaws in Metallic Structures (BS 7910).* British Standards (BSi), 2007

Brown, K. H., Morrow, C., Durbin, S., & Baca, A. *Guideline for Bolted Joint Design and Analysis: Version 1.0.* Albuquerque, New Mexico : Sandia National Labs, 2008

Cabaleiro, M., Moutinho, C., González-Gaya, C., Caetano, E., & Rosales-Prieto, V. F. Analysis of Stiffness of Clamped Joints versus Bolted Joints in Steel Structures by Means of Accelerometers and Shaking Table Tests. *Sensors (Basel), Vol. 21,* No. 14, pp. 4778, 2021

Dinardo, G., Fabbiano, L., & Vacca, G. A smart and intuitive machine condition monitoring in the Industry 4.0 scenario. *Measurement, Vol. 126*, 1-12, 2008

Gray, P. Stress corrosion cracking of rock bolts. *Coal Operators' Conference,* 1998

Hou, J., Wicks, B. J., & Antoniou, R. A. An investigation of fatigue failures of turbine blades in a gas turbine engine by mechanical analysis. *Engineering Failure Analysis, Vol. 9*, pp. 201-211, 2002

Hudgins, A., James, B., & FASM. Fatigue of Threaded Fasteners. *ADVANCED MATERIALS & PROCESSES*, pp. 18-22, 2014

Hui-li, W., & Si-feng, Q., High-Strength Bolt Corrosion Fatigue Life Model and Application. *The Scientific World Journal, 2014*.

Karthikeyan, M., & Subashini, T. S., Automated object detection of mechanical fasteners using faster region based convolutional neural networks. *International Journal of Electrical and Computer Engineering (IJECE), Vol. 11*, No. 6, pp. 5430-5437, 2021

Kim, J., Yoon, J.-C., & Kang, B.-S. Finite element analysis and modeling of structure with bolted joints. *Applied Mathematical Modelling, Vol. 31, No.* 5, pp. 895-911, 2007

Lee, H.-C., Choi, J.-m., Lee, B., & Kim, T.-G. Failure analysis of stress corrosion cracking in aircraft bolts. *Engineering Failure Analysis, Vol. 14, No.* 1, pp. 209-217, 2007

Levy, M., & Salvadori, M. *Why Buildings Fall Down: How Structures Fail.* Norton & Company, 2002

Mohammadizadeh, M., Lu, H., Fidan, I., Tantawi, K., Gupta, A., Hasanov, S., . . . Rennie, A. Mechanical and Thermal Analyses of Metal-PLA Components Fabricated by Metal Material Extrusion. *Inventions, Vol. 5, No.* 3, pp. 44, 2020

Molaei, S., Alizadeh, R., Attarian, M., & Jaferian, Y. A failure analysis study on the fractured connecting bolts of a filter press. *Case Studies in Engineering Failure Analysis, Vol. 4*, pp. 26-38, 2015.

National Transportation Safety Board. *NTSB Identification: WPR14LA238.* National Transportation Safety Board, 2015, Retrieved 3 11, 2015

Naval Surface Warfare Center Carderock Division. *Handbook of Reliability Prediction Procedures for Mechanical Equipment.* Logistics Technology Support, West Bethesda, Maryland, 2010
Oberg, E., Jones, F., Holbrook, L., & Ryffel, H. *Machinery's Handbook, 28th Edition.* New York: Industrial Press, 2008
Pantić, Z., Ballinger, R. G., & Bambei, J. H. *MWRA MetroWest Water Supply Tunnel Shaft 5A Pipe Break Pipe Failure Scenario Report.* Boston, MA: Massachusetts Water Resources Authority, 2011
PARIS, P., & ERDOGAN, F. A critical analysis of crack propagation laws. *J. Basic Eng., Vol.85, No.* 4, pp. 528-533, 1963
Robinson, J. A. *Statistical Analysis of Failure Strengths in Industrial Fasteners.* Carbondale, IL: ProQuest, 2006
Swedish Accident Investigation Authority. *Slutrapport RO 2017:01.* Stockholm, Sweden, 2017
Tantawi, H. M., Ali, J., & Tantawi, K. H. Investigation of Statistics of Failure Modes and Locations in Bolts. *Tennessee Academy of Science Collegiate Meeting.* Nashville, TN, 2015
Tantawi, K. H., & Tantawi, H. M. Bolt failure due to low-cycle fatigue. *Journal of the Tennessee Academy of Science.* Murfreesboro, TN, 2015
Tantawi, K. H., Alazard, D., & Cumer, C. Linear Dynamic Modeling of Spacecraft With Various Flexible Appendages. *Proceeding of The International Federation of Automatic Control*, pp. 11148-11153, 2008
Tantawi, K. H., Oates, J., Kamali-Sarvestani, R., Bergquist, N., & Williams, J. D. Processing of photosensitive APEX™ glass structures with smooth and transparent sidewalls. *Journal of Micromechanics and Microengineering, Vol. 21, No.* 1, 017001, 2010.
Tantawi, K. H., Waddell, E., & Williams, J. D. Structural and composition analysis of Apex™ and Foturan™ photodefinable glasses. *Journal of Materials Science, Vol. 48*, pp. 5316-5323, 2013
Tantawi, K., Berdiev, B., Cerro, R., & Williams, J., Porous silicon membrane for investigation of transmembrane proteins. *Superlattices and Microstructures, Vol. 58*, pp. 72-80, 2013
Tantawi, K., Fidan, I., & Tantawy, A. Status of Smart Manufacturing in the United States, *SoutheastCon.* Huntsville, AL, 2019
Tantawi, K., Fidan, I., Musa, Y., & Tantawy, A. Smart Manufacturing: Post-Pandemic and Future Trends. In *Applied AI and Multimedia Technologies for Smart Manufacturing and CPS Applications* (pp. 278-300). IGI Global, 2023
Tantawi, K., Sokolov, A., & Tantawi, O. Advances in Industrial Robotics: From Industry 3.0 Automation to Industry 4.0 Collaboration. *4th Technology Innovation Management and Engineering Science International Conference (TIMES-iCON).* Bangkok, Thailand, 2019.
Terry, S., Lu, H., Fidan, I., Zhang, Y., Tantawi, K., Guo, T., & Asiabanpour, B. The Influence of Smart Manufacturing Towards Energy Conservation: A Review. *Technologies, Vol. 8*, No. 31, 2020
Unbrako. *The Cause and Prevention of Fastener Fatigue Failure, 2001.* Retrieved 4 9, 2015, from http://unbrako.com/facts.htm
Wagle, S., & Kato, H. Ultrasonic detection of fretting fatigue damage at bolt joints of aluminum alloy plates. *International Journal of Fatigue, Vol. 31*, pp. 1378-1385, 2009

Biographies

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