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A Review on the Impact of Surface Coatings on Fatigue Life of Welded Joints

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ABSTRACT: The effects of various coatings on fatigue life can be either negative or positive, depending on many parameters and such effects can be hardly predicted. The current review discusses the impact of coatings on welded joints with respect to their fatigue lives. The scope of the review also includes the discussion of factors influencing fatigue life of welded joints, fatigue life estimation methods and coatings technology.

KEYWORDS: Fatigue Testing Machine (FTM), High Strength Steel and surface coating.

I. INTRODUCTION

Numerous methods of surface treatment has been developed in the past for the purpose of increasing strength and extension of lifetime of the engineering components. For strength and failure resistance, the most sensitive part of component is its surface for reasons that the surface is directly exposed to unfavorable action of the environment and also the place with the best conditions for nucleation and growth of cracks. The resistance in the individual cases can be increased by various means depending on the substrate material and on the character of loading and environment. A desired properties of the surface layer can be achieved by two principal methods of surface treatment: One is that the surface layer on the substrate is modified with changing the composition or microstructure by chemical, thermochemical, thermal or mechanical action. The other is that the surface layer is created on the substrate surface by coating from other material.

The fabrication of a thin layer of ceramics on the surface of various engineering components by a variety of techniques has received considerable attention in past few years. A number of superior properties of ceramics thin film produced by physical vapor deposition (PVD) or chemical vapor deposition (CVD), such as, high hardness, high resistance to wear, chemical stability, corrosion resistance and relatively good adhesion of the films and an attractive color, may be attributed to surface improvement of metals.

Fatigue analysis of a component made of single material itself is complex as there can be several reasons for failure due to fatigue. Dominique Beghin (2006) quoted that, fatigue life prediction of welded joints is complex, costly and time consuming, due to the diversity of stress concentration locations and heterogeneity of the weld metal properties. Extensive research is done on fatigue life prediction of welded joints, as fatigue is one of the main reasons, for the failure in welded joints; however, the research is not exhaustive. There is still lot of scope for exploration in this area, due to the continuous inventions of newer materials, welding techniques and engineering designs. Coatings are widely employed in gears to keep interface from wearing excessively. Coating is an effective way to enhance service life. The slide-roll contact under lubrication of gear leads to complicated sub-surface stress state and the stress concentrating at shallow surface. Coating materials deposited onto various substrates have been extensively used in the aerospace, automotive and petrochemical fields, in recent years. Chromium plating is the most used electrodeposited coating to



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obtain high level of hardness, resistance to wear and corrosion and low coefficient of friction, although problems concerning chrome plating are resulting in search to identify economically viable alternatives.

The effect of tungsten carbide thermal spray coating applied by HP/HVOF process and hard chromium electroplating for the rotating bending tests, was to decrease the fatigue strength for AISI 4340 steel. The influence is more significant in high cycle fatigue tests than in low cycle fatigue tests. The decreasing of the fatigue strength was higher in chromium electroplated specimens than in tungsten carbide coated specimens. 2001

II. FACTORS INFLUENCING FATIGUE LIFE OF WELDED JOINTS

Pollard et al. (1972) proposed that geometry of weld is the most important aspect in arriving at the fatigue properties of a weld. Different welding processes influence fatigue strength by producing welds with different degrees of surface roughness and weld metal soundness. It was also concluded that automatic processes prove to be superior to manual processes because they can produce welds with a smoother surface and greater freedom from weld defects such as porosity and slag inclusions. Residual stress due to welding can affect fatigue strength and a moderate increase in fatigue strength can be obtained by thermal stress relief. Localized heating, localized heating and quenching, localized compression and peening proved to be effective in inducing the required compressive stresses and thereby enhancing fatigue strength. The post weld treatments involving local heating or compression are only suitable for treating the ends of longitudinal fillet or gusset welds, whereas peening is applicable to all weld geometries. The microstructures of the weld metal and heat-affected zone have only a negligible impact upon the fatigue strength of welds and are usually masked by the much greater effects of weld geometry and weld defects.

Piraprez (1982) examined the effect of preheating and shot-peening, on the fatigue strength of oxygen cutting surfaces. Based on the fatigue test results, shot-peening after cutting increased the fatigue resistance, by 30MPa to 35MPa and preheating by about 25MPa, for AE 355 steel.

Sperle (1997), in his survey of high strength steels with yield, stress up to 1200MPa found that, material strength has no influence on the fatigue strength of welded joints. The reason was the sharp notch or crack at the weld toes. It was also reported that, when the stress concentration is moderate, the yield strength of the base material can affect the fatigue resistance.

Rörup et al. (2004), investigated the influence of mean compressive stresses on the fatigue resistance of a S355 J2 G3 steel welds, fabricated by longitudinal stiffener employing fillet welds. The specimens were made from structural steel S355 J2 G3. It was concluded that, the magnitude of residual stresses influenced the fatigue life resistance of the material, significantly [6].

Johan Martinsson (2005) concluded that, weld geometry and defects strongly influence the fatigue life of the welds and further concluded that, the flux core wire gave low magnitude of defects, compared to solid wire. Also, the importance of applying boundary conditions correctly increases, when the fatigue critical locations are close to the boundary.

Barsoum et al. (2009), examined the residual stress effect on the fatigue life of welded structures. In this investigation, the FE-method was used in residual stress state determination. The temperature results from the FE-models were compared with measured results and concluded that, the compressive residual stresses had a beneficial influence on the fatigue resistance.



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FATIGUE LIFE ESTIMATION METHODS

The popular fatigue life assessment methods can be classified as follows;

- Global Methods
 - o Nominal stress method.
- Local Methods
 - Hot spot method
 - o Local stress method
 - o Local strain method
 - Fracture mechanics method

Balasubramanianet. al. (1999), developed a new mathematical model, to predict the fatigue life of Shielded Metal Arc Welded (SMAW) cruciform joints, containing Lack of Penetration (LOP) defect using High strength, quenched and tempered steel (ASTM 517 'F' Grade), as the base material. The model was developed by Response Surface Method (RSM) and Analysis of Variance (ANOVA) technique, was applied to check the validity of the model. By the developed mathematical model, fatigue life could be predicted with 99% confidence level, for the above-mentioned type of welded joints. The effect of cruciform joint dimensions on fatigue life was analysed in detail and concluded that larger weld sizes, smaller LOP sizes and straight profile fillet welds have better fatigue lives, compared to other combinations.

, on arc welded Steel and Aluminum structures, subjected to fatigue loading. The effect of weld improvement methods, like modification of weld toe geometry by burr grinding, TIG dressing, introduction of compressive residual stresses by hammer/ needle peening on fatigue life of a weld were discussed.

Lassen et. al. (2005), investigated a statistical model, where fatigue life and fatigue limit were treated as random variables. Fatigue failure can arise even under modest in-service stresses. Besides, fatigue lives exhibit significant scatter, even under constant amplitude loading in controlled pre-defined conditions. This phenomenon makes statistical approaches inevitable and fatigue life, must be predicted at given probability levels of failure, under defined environment and loading conditions, for a given welded detail. The most common approach is to assume that, the nominal applied stress range is the key parameter for the fatigue life, and those other loading parameters, such as the mean stress has a minor effect for welded joints.

A. Chattopadhyay et al. (2011), proposed an efficient shell finite element technique, for obtaining stress data in welded structures relevant for fatigue analyses and showed that, the complete welded structure could be modelled using small number of large shell finite elements. The proposed technique could capture both, the magnitude and the gradient of the hot spot stress, near the weld toe which were necessary to calculate the stress concentration and the peak stress, at critical cross-sections like the weld toe.

Hong-Tae Kang et. al. (2012), discussed the primary mechanical parameters, affecting fatigue life of resistance spotwelded joints, which include weld nugget diameter, specimen width, sheet metal thickness, base metal strength, specimen types, and multiaxial loading. Fatigue life prediction methods for spot-welded joints were also discussed, by categorizing them into three approaches, i.e. Load life approach, Linear elastic fracture mechanics approach and Structural stress approach.

TeppeiOkawaet. al. (2013), developed a fatigue life prediction system for welded structures on crack growth analysis. In that system, the fatigue life was predicted considering the effects of the residual stress and the load sequences by the crack opening and closure simulation. The effects of fatigue strength improvement techniques, such as UIT (Ultrasonic Impact Treatment), were accurately predicted by the new system.

Mikheevskiyaet. al. (2015) proposed a novel method named Total Life approach, which when applied to welded A-36 steel T-Joint configuration, generated a reasonable estimation of the total fatigue life of the component. This was done by using only the Total Life fatigue crack growth analysis technique, for both constant and variable amplitude loading histories. This enabled, estimating the entire fatigue life of a component, without the need of using division of the



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fatigue process into crack initiation and propagation stages. It required using only one methodology, i.e., the fracture mechanics based fatigue crack growth analysis. It was also demonstrated that, the Total Life fatigue crack growth method can be used to estimate fatigue lives of smooth specimens that are deemed to be free of initial cracks in engineering sense.

D. Radraj (2015), proposed a local SED approach which provides powerful tools, to solve the field problem at sharp notches, thus facilitating the assessment of brittle fracture and fatigue failure of structural members. The size effect on strength was also included. Due to the proposed approach, finite element procedures based on coarse meshes were sufficient, without major loss in accuracy.

Shrestha Ranjit et al. (2016), predicted the fatigue life of dissimilar materials welded specimen, using Finite Element Analysis. The study was carried on welding of two dissimilar materials, in which SA106 and STS 304 are the parent materials and M309 is used, as a filler material. Butt welded joint specimen using gas metal arc welding (GMAW) process, was analysed to cyclic loading. The specimen was modelled in ANSYS 15 Workbench. The maximum life was found to be 1E7 cycles, whereas the minimum life was found to be 2.53E5, for the given boundary conditions. The phenomenon of fatigue is generally divided into three steps: (1) crack initiation, (2) crack

growth/propagation and (3) final fracture. The first two steps of the process are not easy to characterize and a great amount of work on research has been performed to try to understand the mechanisms involved on each one of them; it is even hard to identify a sharp limit to divide when the crack initiation ends and the crack propagation starts. The four main parameters can influence the fatigue strength:

- Stress difference, or as most often called *stress range*,
- Structural detail geometry,
- Material characteristics,
- Environment

The typical fatigue behavior of most metals at dry conditions shows a stress level low enough at which the metal will no longer fail under fatigue, and it is said that the material shows infinite life. For instance, in Figure 4 a runout (no failure) is observed for each of the curves at certain stress level; taking the unnotched curve as example, the runout is present at 345 MPa. This maximum stress that the material can endure without failure is called fatigue (endurance) limit. Below this stress level there is a 50% probability that no failure will occur on a material at the same conditions. Most nonferrous metals and ferrous metals under corrosive environments do not exhibit an endurance limit. In such cases, the S-N curve does not even out at certain stress value, but instead it continues falling at a slow rate at high number of cycles. When this happens, fatigue strength, rather than fatigue limit, is reported. Fatigue strength is defined as the stress level that a material can withstand to reach a defined number of cycles, generally enough to beconsidered as 'infinite life'. In these cases, the plot must specify the number of cycles at which the fatigue strength is reported. A typical endurance limit behavior is shown in Figure 5 for AISI 1045 steel; in the same plot, the constant drop in stress to reach longer life can be seen for aluminum 2024-T6.

One of the methods to improve the fatigue life of the materials is surface treatments, sometimes referred to as postprocessing. They play a very important role in the appearance, function and life of the product. Broadly, these are processes that affect either a thin layer on the surface of the part itself, or add a thin layer on top of the surface of the part. There are different coating and surface treatments processes, with different applications, uses, etc. The important uses include:

- Improving the hardness
- Improving the wear resistance
- Controlling friction, Reduction of adhesion, improving the lubrication, etc.
- Improving corrosion resistance
- Improving aesthetics



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These are different types of surface coating methods and their effect on the fatigue life of the materials.

Coating deposition methods

For many years it has been possible to deposit a wide range of hard and wear resistance coatings on substrates using either chemical deposition or physical deposition. The deposition process is very dependent on the degree of flexibility in terms of the substrates and coating materials. The ideal fabrication process is one which can give good quality such as a dense, homogeneous coated surface and excellent adhesion to the substrate. The deposition parameters play a crucial role in defining the film properties. Figure 3 presents the coating methods used in the papers selected for the review.



Figure-1: General coating methods in producing coating materials for joint prostheses.

PVD consists of the generation of plasma metal ions that are transported by an electric field to the surface to be coated. The physical deposition method has the ability to vary the deposition parameters over a wide range. The components forming the film are charged with high energies and deposited on a substrate with particular structural and thermal states. The method can be used to deposit almost any type of inorganic material as well as some kinds of organic materials. PVD coatings are more corrosion resistant than coatings applied by the electroplating process. However, a high capital cost is required with a large amount of heat dissipated in cooling systems. The rate of deposition is usually quite slow. Nanocomposite films with enhanced adhesion to Ti–6Al–4 V alloy substrates were successfully deposited by one of the physical deposition methods called pulsed laser deposition. The laser surface modification technique offers a high range of process controllability and flexibility. The advantages of the laser surfacing technique include chemical cleanliness, distortion, controlled thermal penetration and the ease to automate.

CVD is the process of a chemically reacting volatile compound of a material to be deposited. Reaction occurs when other gases or condensation of a compound from the gas phase onto substrate to form a solid deposit. Highly pure materials with structural control at the atomic or nanometre scale can be produced using CVD at low processing temperatures. CVD has the capability for producing coatings of complex shape engineering components and the fabrication of nano-devices and ceramic matrix composites.

The methods and parameters for depositing the coating materials on different types of substrates are listed in Balagna et al. studied the properties of coated materials at 970 and 990 °C. Ta-enrichment was found to be greater at 970 °C



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than 990 °C. Furthermore, coating quality was lower at the shorter time, 30 min, and corrosion occurred at the longer time, 60 min. The ideal time frame for the coating process was 45 min because it had the maximum weight increment.

III. CONCLUSION

The impact of coatings on the fatigue life of welded joints varies case to case and there is no consistency. In certain cases, the fatigue life declines due to coatings, however the decline may be supported by the increase in some other parameter life corrosion resistance, hardness etc.

REFERENCES

- [1] V. K. Srivastava and R. Prakash, "Study of fatigue life of glass fibre/zirconia hybrid composites using an ultrasonic technique," *Int. J. Fatigue*, vol. 9, no. 2, pp. 109–113, 1987.
- [2] M. P. Nascimento, R. C. Souza, W. L. Pigatin, and H. J. C. Voorwald, "Effects of surface treatments on the fatigue strength of AISI 4340 aeronautical steel," *Int. J. Fatigue*, vol. 23, no. 7, pp. 607–618, 2001.
- [3] W. Pyda, "The relation between preparation, microstructure and mechanical properties of spherical yttria-zirconia powders," *J. Eur. Ceram. Soc.*, vol. 17, no. 2, pp. 121–127, 1997.
- B. Lonyuk, I. Apachitei, and J. Duszczyk, "The effect of oxide coatings on fatigue properties of 7475-T6 aluminium alloy," Surf. Coatings Technol., vol. 201, no. 21 SPEC. ISS., pp. 8688–8694, 2007.
- [5] K. N. P. D. Kumar, "Study on Thermal Fatigue Behaviour of Plasma Sprayed Yttria Zirconia TBC System on Aluminium Alloy," Int. J. Mech. Prod. Eng., vol. 2, no. 3, pp. 19–22, 2014.
- [6] H. A. Ching, D. Choudhury, M. J. Nine, and N. A. Abu Osman, "Effects of surface coating on reducing friction and wear of orthopaedic implants," Sci. Technol. Adv. Mater., vol. 15, no. 1, 2014.
- [7] I. Černý and D. Mikulová, "Effect of selected types of caoting on fatigue properties of nitrided steel," no. 5, 2010.
- [8] A. Yasir, "Improving the fatigue life of steel bars by using Nano-coating technology," Int. J. Eng. Technol., vol. 3, no. 4, p. 523, 2014.
- J. Jagadesh Kumar, G. Diwakar, and V. V Satyanarayana, "CORROSION FATIGUE OF WELDED JOINTS IN MARINE AND NAVAL STRUCTURES : A REVIEW," vol. 7, no. 6, pp. 155–162, 2017.
- [10] D. Wattanasiriwech, S. Wattanasiriwech, and R. Stevens, "A sol-powder coating technique for fabrication of yttria stabilised zirconia," *Mater. Res. Bull.*, vol. 41, no. 8, pp. 1437–1446, 2006.
- [11] S. Metallurgica and M. Vol, "Brittle Surface Coatings," vol. 29, no. c, pp. 237–242, 1993.
- [12] J. Gu, X. Wu, H. Cuypers, and J. Wastiels, "Transactions on Engineering Sciences vol 21, © 1998 WIT Press, www.witpress.com, ISSN 1743-3533," vol. 17, no. Cvd, pp. 589–598, 1998.
- [13] S. Baragetti and F. Tordini, "A Review of the Fatigue Behavior of Components Coated with Thin Hard Corrosion-Resistant Coatings," *Open Mater. Sci. J.*, vol. 4, pp. 9–17, 2011.13. Haagensen, P. J. Maddox, S. J., "IIW Recommendations on Post Weld Improvement of Steel and Aluminium", IIW Commission XIII, 2001.
- [14] T. Lassen, Ph. Darcis, And N. Recho, Fatigue Behavior of Welded Joints Part 1 Statistical Methods for Fatigue Life Prediction, Supplement to The Welding Journal, page 183-187, December 2005.
- [15] A Chattopadhyay, G. Glinka, M. El-Zein, J. Qian, and R. Formas, "Stress Analysis and Fatigue of welded structures," Welding in the World, Vol. 55, Issue. 7-8, page 2-21, 2011.
- [16] Hong-Tae Kang & Yung-Li Lee, "Fatigue Life Prediction Methods of Resistance Spot-Welded Joints", Metal Fatigue Analysis Handbook, page 429-460, 2012.
- [17] Teppei Okawa, Tetsuro Nose, Hiroshi Shimanuk, Tamaki Suzuki, "Fatigue Life Prediction of Welded Structures Based on Crack Growth Analysis", Nippon Steel Technical Report No. 102, page 51-56, January 2013.
- [18] D. Radaj, "State-of-the-art review on the local strain energy density concept and its relation to the J -integral and peak stress method", Fatigue & Fracture of Engineering Materials & Structures, Vol. 38, Issue 1, page 2-28, 2015.