

# Research Impact of Conserving Large Military Vehicles through a Sustainable Methodology

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## Abstract

The objective of this paper is to present the research impact, significance and reach made for British military Heritage. An effective knowledge exchange model is being developed in terms of substantial contribution to the identification, measurement, analysis, prediction and condition monitoring of structural failures within military tanks with enormous societal and economic impact. This is the first evidence based research carried out in this field and is directly linked to the development of a new conservation facility, further research and grants.

*Keywords: Large Vehicles, Impact, Corrosion, Sustainable*

## 1 Introduction

With the imminent centenaries of the First World War and the passing of the Generation that fought in the Second World War, the conservation of significantly deteriorating military tanks which are one of the classic examples of British Engineering Heritage has taken on a new prominence. To implement a framework able to oversee and as a result retard structural deterioration; a research collaboration was established between the Tank Museum at Bovington and Bournemouth University. During this project a process of developing a sustainable framework to slowdown structural degradation through corrosion and wear begun with the objectives to; a) identify, measure, analyse, predict and retard corrosion failures b) develop a condition monitoring framework based upon advanced sensors and c) the commencement of an improved approach to

safeguard and withstand military tanks stationed inside and outside the shelters in the Tank Museum cost effectively.

This paper aims to elaborate on the overall research significance, contributions to the British Military Heritage & stakeholder and societal impact [1-17].

## **2 Structural Failures Mitigation Programme**

Research started with a specific aim to address the increasing problems of structural deterioration due to corrosion and component failures in The Tank Museum Vehicles. This research has started;

- The development of a model to; identify, measure, analyse, predict and retard structural failures.
- The development of an in-situ condition monitoring framework to identify and monitor corrosion in the structures.
- The initiation of an optimised approach to protect and sustain military tanks stationed inside and outside the shelters.

### **2.1 Structural Failures**

Research conducted with the Tank Museum has presented many challenges as the literature and knowledge of the materials/components utilised, design process and manufacturing techniques were missing and incomplete. The history of the service life incorporating operational and environmental conditions under which the vehicles operated previously are incomplete and in many cases unknown. Extensive experimental research to; identify, measure, analyse, predict and monitor structural failures was conducted on 20 vehicles. This research provided important information on the severity of corrosion problem in vehicles as shown in Figure 1. Other structural failures associated with corrosion directly and/or indirectly were also identified as shown in Figure 2. Through advanced materials characterisation techniques, the material composition; which was processed in the 2<sup>nd</sup> World war was obtained; this was followed by extensive research programme in corrosion failure analysis [1, 4].



Figure 1 Corrosion Problems in Saladin Armoured Car



Figure 2 (a) Crack Propagation in Mark II Hull (b) Suspension Failure in Jagdpanther, sdkfz 173 [18]

## **2.2 Environmental Monitoring**

Relative humidity and temperatures variations strongly influence structural deterioration due to corrosion. It was identified in this research that variations in the relative humidity and temperatures were not viable to keep the tanks safe against structural failures. As a result; the monitoring of relative humidity and temperatures has started at 10 different locations and variations are now constantly monitored. The monitoring mechanisms of such parameters and as a result keeping the variations to a minimum will help towards conservation of the vehicles sustainably [2].

## **2.3 Corrosion Monitoring**

An advanced method to condition monitor structural failures due to corrosion has been put in place on the 2 tanks. This methodology provides the opportunity to collect data in real time when the corrosion starts to occur on the tanks surfaces. This is one of the most innovative methodologies to oversee corrosion initiation and propagation. The Tank Museum at Bovington is believed to be the only museum in the World with condition monitoring system on their vehicles. The data composed through this framework is very important in-terms of providing a sustainable methodology to conserve military tanks cost effective methodology.

## **2.4 Corrosion Modelling**

Corrosion data obtained from through condition monitoring technique has been utilised to simulate corrosion tests experimentally for the purpose of life expectancy programme. These experimental results research have been utilised to model corrosion in certain environments. Data from the live corrosion monitoring and experimental results has been compiled and the process of designing an empirical model to develop a life expectancy and longevity programme for military tanks has started [11, 16, 19].

# **3 Research Impact**

## **3.1 Knowledge Dissemination**

Research with the Tank Museum has attracted substantial interest from wider research community. Table 1 provides some of our most read and cited papers published. Three out of four papers have made it to the most read articles in the Journal of Adhesion Science and Technology (JAST) Taylors and Francis. One of our paper [10] is the most read paper (Article read = 1948) making to the top of list in just a few months and has retained its position for 11 months' after publishing. The other two article [12, 20] are at 8<sup>th</sup> and 11<sup>th</sup> positions with 658 and 555 reads respectively and has retained their position for the past 6 - 8 months.

Another article [11] which is open access in JAST is also contributing a lot in the coating durability field which can be seen in terms of citations. The article has been cited 5 times in just 4 months from its publication (11<sup>th</sup> Aug 2015). This research is linked with successfully completed research in collaboration with The Tank Museum.

Table 1 List of the Most Downloaded Published Articles in year 2015

<b>S No</b>	<b>Article Title</b>	<b>Citations</b>	<b>Publication Year</b>
1	Modelling of metal-coating delamination incorporating variable environmental parameters	9	2015
2	Optimisation of interface roughness and coating thickness to maximise coating–substrate adhesion–a failure prediction and reliability assessment modelling	8	2015
3	A unified mathematical modelling and simulation for cathodic blistering mechanism incorporating diffusion and fracture mechanics concepts	8	2015
4	A holistic mathematical modelling and simulation for cathodic delamination mechanism–a novel and an efficient approach	5	2015
5	Material characterization and real-time wear evaluation of pistons and cylinder liners of the Tiger 131 military tank	7	2013
6	Corrosion Damage Analysis and Material Characterization of Sherman and Centaur-The Historic Military Tanks	9	2013

### 3.2 Impact on Museums

This research has worked as a connection among the museums in UK and Europe. Informed research activity with the Tank Museum has resulted The National Museum sector steering committee, meetings of national and international museum level were held including at Bournemouth University regularly; to define good practice of large object preservation within various environments and operating conditions to maximise public value. Research with the Tank Museum has attracted significant public interest and successful EU Museums Conference on 2<sup>nd</sup> July 2012 at BU is one of the examples of evidence of impact.

### 3.3 Conservation Centre

Recommendation from this research has helped towards securing £2.5 million Heritage Lottery Fund to build a new conservation centre in the Tank Museum shown in Figure 3. The new facility (3,700 sq. m) can accommodate most of the museum tanks to be protected against environmental assisted damage and provides the opportunity for the on-going volunteered-led conservation and preservation programme aimed at diminishing corrosion failures through a non-invasive and cost effective way.



Figure 3: image courtesy of the Tank Museum - Building of the New Conservation Facility at the Tank Museum

### **3.4 Societal Impact**

The Tank Museum attracts approximately 200,000 visitors every year. This research aims to extend the life expectancy of the military heritage in the Tank Museum Bovington. This means that the British Public and future generation could enjoy the British Engineering Legacy from the Great Wars for a longer time.

During the course of this project research work was conducted on Tiger 1 main battle tank [1]. This created an important public engagement through YouTube following. Over one million YouTube following has been observed so far. This is a clear indication of British public interaction with our research through the Tank Museums collection.

#### **3.4.1 STEAM School Programme**

One of the most exciting public engagements due to this research was the Bournemouth University, Tank Museum and Harewood College to work together to arrange the Science, Technology, Engineering, Arts and Maths programme (STEAM) for secondary school children in January every year. Children from Secondary Schools across Dorset County UK are divided into teams to compete against each other to successfully negotiate an obstacle course using Lego tanks that they have designed and built themselves.

This activity provide an opportunity to the Secondary School Pupils to participate in small engineering projects by taking part in practical, hands on competition.

#### **3.4.2 Purbeck at War and Science School Club**

The Purbeck at War project is run by Purbeck School and funded by the Heritage Lottery Fund, and aims to help young people better understand the effect of war on the local landscape and society. As part of the project pupils from local primary schools visit the Tank Museum for a day of activities themed around the First World War.

The Tank Museum provided the necessary support to Purbeck School pupils to discover the remains of trenches in the north of Bovington that were originally dug for the first tank crews to practice. School pupils used GPS devices to sketch the trench systems.

The Tank Museum provides the opportunity to Lulworth and Winfrith schools of “Science after School Club” for star pupils every half term. During the after school science club the children are shown; how to float a tank; built a projectile launcher and construct a bridge to support the weight of a remote control vehicle. This helps motivate pupils to upsurge their knowledge of science and engineering. Not only this activity provides a knowledge base for children, but is also an opportunity to make new friends and learn teamwork skills.

## 4 Conclusions

This paper has elaborated on the research impact of the sustainable methodology for conserving military tanks in the museum environment. Advanced research methodologies were deployed during this research to identify, measure, analyse, predict and monitor structural failures. This research has contributed significantly to research through the distribution of journal and conference publications.

Through an effective knowledge exchange programme general Public engagement has been attracted, the dissemination of the research knowledge has started to the future generations, accessing future funding and new opportunities have been pursued and through advanced research informed decisions can be made to preserve British Engineering Heritage against structural failures sustainably.

## References

- [1] A. Saeed, Z. A. Khan, M. Hadfield, and S. Davies, "Material characterization and real-time wear evaluation of pistons and cylinder liners of the tiger 131 military tank," *Tribology Transactions*, vol. 56, pp. 637-644, // 2013.
- [2] A. Saeed, Z. A. Khan and Montgomery, E., "Corrosion Damage Analysis and material Characterization of Sherman and Centaur - The Historic Military Tanks," *Materials Performance and Characterization*, vol. 2, pp. 30-44, February 6, 2013.
- [3] K. Wilton-Smith, Z. A. Khan., A. Saeed and M. Hadfield "Accelerated corrosion tests of waste-gated turbocharger's adjustable and fixed end links," presented at the International Conference on High Performance and Optimum Design of Structures and Materials, 9 - 11 June, 2014 Ostend, Belgium 2014.
- [4] A. Saeed, Z. A. Khan., N. Garland and R. Smith "Material characterisation to understand various modes of corrosion failures in large military vehicles of historical importance.," presented at the Fifth International Conference on Computational Methods and Experiments in Materials Characterisation, 13 - 15 June 2011, Kos, Greece, 2011.
- [5] A. Saeed, Z. A. Khan, M. Clark, N. Nel, and R. Smith, "Non-destructive material characterisation and material loss evaluation in large historic military vehicles," *Insight: Non-Destructive Testing and Condition Monitoring*, vol. 53, pp. 382-386, 2011.
- [6] Z. A. Khan, M. Grover, and M. H. Nazir, "The Implications of Wet and Dry Turning on the Surface Quality of EN8 Steel," in *Transactions on Engineering Technologies*, ed: Springer, 2015, pp. 413-423.



- [7] Z. A. Khan, P. Pashaei, R. S. Bajwa, M. H. Nazir, and M. Camak, "Fabrication and characterisation of electrodeposited and magnetron sputtered thin films," *International Journal of Computational Methods & Experimental Measurements*, 3(2) 165-174. doi:10.2495/CMEM-V3-N2-165-174 2015.
- [8] M. Nazir, Z. A. Khan, and K. Stokes, "A unified mathematical modelling and simulation for cathodic blistering mechanism incorporating diffusion and fracture mechanics concepts," *Journal of Adhesion Science and Technology*, vol. 29, pp. 1200-1228, 2015.
- [9] M. Nazir, Z. A. Khan, and K. Stokes, "Optimisation of interface roughness and coating thickness to maximise coating–substrate adhesion—a failure prediction and reliability assessment modelling," *Journal of Adhesion Science and Technology*, vol. 29, pp. 1415-1445, 2015.
- [10] M. H. Nazir, Z. Khan, and K. Stokes, "Modelling of metal-coating delamination incorporating variable environmental parameters," *Journal of Adhesion Science and Technology*, vol. 29, pp. 392-423, 2014.
- [11] M. H. Nazir, Z. A. Khan, and K. Stokes, "A holistic mathematical modelling and simulation for cathodic delamination mechanism – a novel and an efficient approach," *Journal of Adhesion Science and Technology*, pp. 1-39, 2015.
- [12] A. Saeed, Z. Khan, and M. Nazir, "An Optimised Approach of Protecting and Sustaining Large Vehicle System," *Sustainability*, vol. 7, p. 15825, 2015.
- [13] Z. A. Khan, M. Hadfield, S. Tobe, and Y. Wang, "Ceramic rolling elements with ring crack defects--A residual stress approach," *Materials Science and Engineering: A*, vol. 404, pp. 221-226, 2005.
- [14] Z. A. Khan and M. Hadfield, "Manufacturing induced residual stress influence on the rolling contact fatigue life performance of lubricated silicon nitride bearing materials," *Materials & Design*, vol. 28, pp. 2688-2693, 2007.
- [15] Z. A. Khan, M. Hadfield, and Y. Wang, "Pressurised chamber design for conducting rolling contact experiments with liquid refrigerant lubrication," *Materials and Design*, vol. 26, pp. 680-689, 2005.
- [16] M. Nazir, Z. Khan, A. Saeed, and K. Stokes, "Modelling the Effect of Residual and Diffusion induced Stresses on Corrosion at the Interface of Coating and Substrate," *Corrosion Journal*, 2015, doi:10.5006/1804.
- [17] C. S. Ramesh, H. Adarsha, S. Pramod, and Z. Khan, "Tribological characteristics of innovative Al6061-carbon fiber rod metal matrix composites," *Materials and Design*, vol. 50, pp. 597-605, 2013.

- [18] A. Saeed, "Sustainable methodology of conserving historic military vehicles," Bournemouth University, 2013.
- [19] M. H. Nazir, Z. A. Khan, A. Saeed, and K. Stokes, "The propagation and axisymmetric stability of circular, defect driven coating delamination under the influence of compression and diffusion induced stress," *Engineering Fracture Mechanics*, Elsevier [Submitted], 2015.
- [20] M. H. Nazir, Z. A. Khan, A. Saeed, and K. Stokes, "A model for cathodic blister growth in coating degradation using mesomechanics approach," *Materials and Corrosion*, 2015, DOI: 10.1002/maco.201508562