Archives
of Materials Science
and Engineering

Volume 115
Issue 2
June 2022
Pages 76-85

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

DOI: 10.5604/01.3001.0016.0755

Formulating delamination-fretting wear failure predictive equation in HAp coated hip arthroplasty using multiple linear regression model

M. Nagentrau [a,*], N.H. Ibrahim [b], S. Jamian [c], A.L. Mohd Tobi [c]

[a] School of Computer Science and Engineering, Faculty of Innovation and Technology,
Taylor's University, Taylor's Lakeside Campus, Subang Jaya, Selangor, Malaysia
[b] School of Engineering, UOW Malaysia KDU University College, Shah Alam, Selangor, Malaysia
[c] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia,
Batu Pahat, Johor, Malaysia
* Corresponding e-mail address: nagentrau.rau17@yahoo.com
ORCID identifier: https://orcid.org/0000-0002-0736-3467 (M.N.)

ABSTRACT

Purpose: Present paper addresses the formulation of delamination-fretting wear failure predictive equation in HAp-Ti-6Al-4V interface of hip arthroplasty femoral stem component using multiple linear regression model.

Design/methodology/approach: A finite element computational model utilising adaptive meshing algorithm via ABAQUS/Standard user subroutine UMESHMOTION is developed. The developed FE model is employed to examine effect of different HAp-Ti-6Al-4V interface mechanical and tribological properties on delamination-fretting wear behaviour. The FE result is utilised to formulate predictive equations for different stress ratio conditions using multiple linear regression analysis.

Findings: Delamination-fretting wear predictive equations are successfully formulated with significant goodness of fit and reliability as a fast failure prediction tool in HAp coated hip arthroplasty. The robustness of predictive equations is validated as good agreement is noted with actual delamination-fretting wear results.

Research limitations/implications: The influence of different mechanical and tribological properties such as delamination length, normal loading, fatigue loading, bone elastic modulus and cycle number under different stress ratio on delamination-fretting wear failure is analysed to formulate failure predictive equations.

Practical implications: The formulated predictive equation can serve as a fast delamination-fretting wear failure prediction tool in hip arthroplasty femoral stem component.

Originality/value: Limited attempt is done to explore the potential of utilizing multiple linear regression model to predict failures in hip arthroplasty. Thus, present study attempt to formulate delamination-fretting wear failure predictive equation in HAp -Ti-6Al-4V interface of hip arthroplasty femoral stem component using multiple linear regression model.

Keywords: Hip arthroplasty, Delamination, Fretting wear, HAp, Regression

Reference to this paper should be given in the following way:
M. Nagentrau, N.H. Ibrahim, S. Jamian, A.L. Mohd Tobi, Formulating delamination-fretting wear failure predictive equation in HAp coated hip arthroplasty using multiple linear regression model, Archives of Materials Science and Engineering 115/2 (2022) 76-85.
DOI: https://doi.org/10.5604/01.3001.0016.0755

BIOMEDICAL AND DENTAL MATERIALS AND ENGINEERING

1. Introduction

Over the past century, there has been a dramatic increase in hip arthroplasty application due to increased osteoarthritis condition [1]. Osteoarthritis is one of the major hip disorders which can lead to a number of complications such as immobility, chronic joint pain and permanent disability. Hip arthroplasty is required to replace the worn hip joint due to osteoarthritis condition. Recent evidence suggests that 88.8% of hip arthroplasty is attributable to osteoarthritis condition [2,3]. High strength, low weight and corrosion resistance are among the interesting characteristics of Ti-6Al-4V alloy to be utilized as common material in hip arthroplasty [4,5]. However, bond between human bone and Ti-6Al-4V hip arthroplasty is required to overcome biocompatibility issue [6,7].

Hydroxyapatite (HAp) is a suitable bio-ceramic material to promote bond between human bone and Ti-6Al-4V hip arthroplasty. However, the effectiveness of HAp coating is greatly challenged in long term usage more than 10 years [8,9]. HAp coated hip arthroplasty femoral stem component is susceptible to delamination-fretting wear failure which can lead to subsequent life-threatening risks such as surrounding organ inflammations and revision surgery [10]. Many researchers attempted to investigate the delamination and fretting wear condition in hip arthroplasty using experimental and numerical approaches. It has been conclusively been shown that hip arthroplasty fretting wear behavior at head-neck junction can be predicted using computational wear modelling method [11,12]. Otsuka et al. [1] and Nagentrau et al. [10] have examined delamination and fretting wear failure behavior at hip arthroplasty femoral stem component using wear modelling approach. It should be noted that costly and high computational time experimental and numerical research are often required to evaluate the fretting wear behavior in hip arthroplasty. This motivates the formulation of maximum delamination-fretting wear depth prediction tool using regression model to assist in reducing the amount of testing required and better design process of HAp coated hip implants.

Regression analysis is one of the statistical tools that can be incorporated in predicting engineering failure [13]. The main objective of regression analysis is to serve as prediction tool by examining the relationship between criterion/dependent and predictor/independent variables [14]. Regression analysis with single and multiple predictor/independent variables are known as simple linear regression and multiple linear regression respectively [13]. In fact, regression model rarely predicts dependent variable in perfect manner. Thus, determination coefficient or known as R square values is often used as an indicator to evaluate regression model goodness of fit. Pradhan et al [15] adopted multiple linear regression analysis to predict landslides and slope failures and he concluded that the predicted outcome shows good agreement with actual data. Multiple linear regression model can assist as fast failure prediction tool in many engineering applications which can minimize costly and time consuming experimental or numerical approaches.

However, limited attempt is done to explore the potential of utilizing multiple linear regression model to predict failures in hip arthroplasty. Thus, present research seeks to formulate delamination-fretting wear failure predictive equation in HAp-Ti-6Al-4V interface of hip arthroplasty femoral stem component subjected to different mechanical and tribological properties using multiple linear regression model. The outcome of this research can serve as novel and fast failure prediction tool.

2. Methodology

2.1. Finite element (FE) model

A finite element (FE) computational model is developed based on modified Archard wear equation to predict delamination-fretting wear. The two-dimensional plane strain case FE model consisting contact pad (bone), HAp (coating) and Ti-6Al-4V (substrate) is modelled to mimic loading condition in HAp coated hip stem arthroplasty. The assigned Young's modulus for contact pad, HAp and Ti-6Al-4V are 1 GPa, 70 GPa and 110 GPa respectively. The loading and boundary condition of FE model is presented in Figure 1a. The FE model is fixed at bottom and side to constrain translational and rotational relative motion. The FE model is subjected to normal and cyclic fatigue stress. The FE mesh module is shows in Figure 1b where

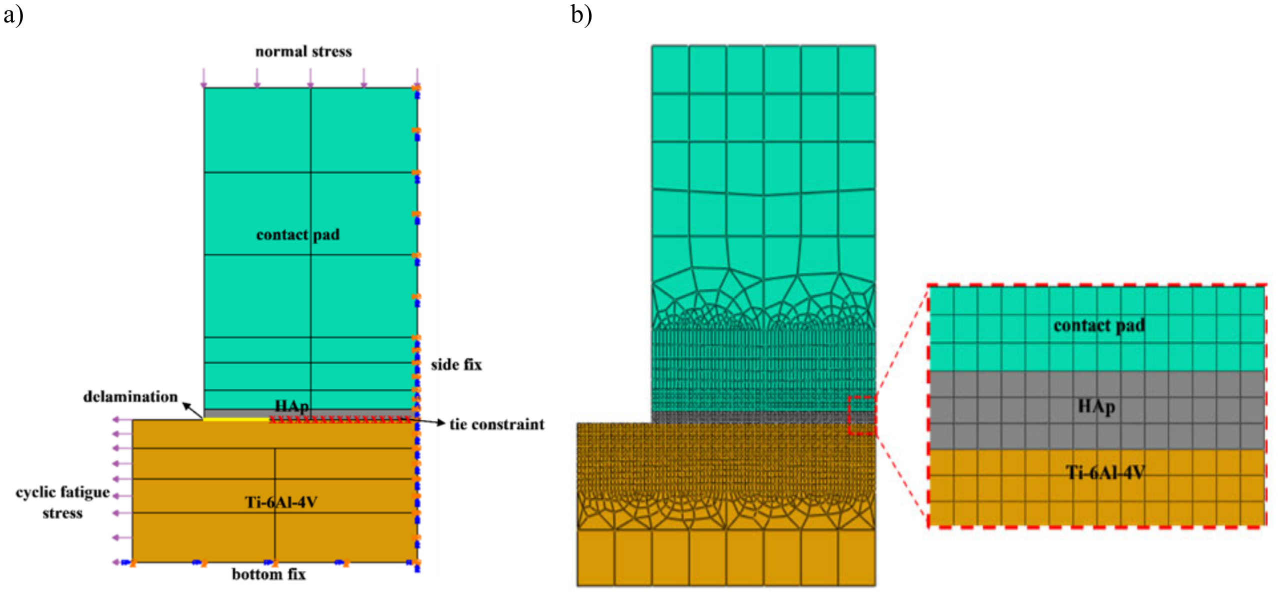

Fig. 1. FE model (a) loading and boundary condition and (b) mesh module

CPE4-A4-node bilinear plane strain quadrilateral elements with 50 µm mesh size assigned at the contact region. The mesh transition from fine to coarse is achieved via edge seeding technique.

Surface to surface contact with Lagrange Multiplier contact algorithm is assigned between HAp coating and Ti-6Al-4V with friction coefficient of 0.7. The delamination length of FE model is controlled using tie constraint approach. The delamination-fretting wear computation is performed using adaptive meshing algorithm via ABAQUS/Standard user subroutine UMESHMOTION. The FE simulation is performed with individual static general steps for 1 second time period (0.02 second increment). 1 million cycle is simulated with appropriate cycle jump of 10,000. Among the focussed mechanical and tribological variables are delamination length (0.25-1.0 mm), normal loading (20-30 MPa), fatigue loading (250-350 MPa), bone elastic modulus (0.1-20.0 GPa) and cycle number (10,000-1000,000) under different stress ratio (R = 0.1, R = 10 and R = -1). The predicted maximum delamination-fretting wear results are recorded in Excel software to formulate predictive equations using multiple regression model to serve as fast failure predictive tool.

2.2. Multiple linear regression model

A multiple regression model is formulated for fast prediction of maximum delamination-fretting wear depth at HAp-Ti-6Al-4V interface in artificial femoral stem component. Regression model is adopted to formulate predictive equation to establish relationship between two or more variables [14-16]. Maximum delamination-fretting wear depth is assigned as dependent variable to indicate severity of failure at HAp-Ti-6Al-4V interface. Meanwhile, independent variables such as delamination length, normal loading, fatigue loading range, bone elastic modulus, number of cycle and stress ratio are assigned as factors that influence dependent variable. Excel multiple regression analysis is most common statistical tool to describe variation of independent variable on dependent variable [17-20].

A multiple linear regression model is employed as independent variables such as delamination length, normal loading, fatigue loading range, bone elastic modulus, number of cycle and stress ratio displaying a linear relationship trend with maximum delamination-fretting wear depth. The multiple linear regression model equation is given as Eq. 1 below:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \dots + b_nx_n \qquad (1)$$

where, y is dependent variable (maximum delamination-fretting wear depth), x's are independent variable (delamination length, normal loading, fatigue loading range, bone elastic modulus, number of cycle and stress ratio) and b's are coefficient of independent variables. The goal of the multiple linear regression model using Excel software is to formulate an appropriate predictive model as a failure prediction tool in terms of maximum delamination-fretting wear depth in order to determine best fitting coefficients from finite element analysis results. The multiple linear regression analysis is performed for four condition, i.e., stress ratio, R = 0.1, R = 10, R = -1 and combined stress ratio respectively.

3. Results and discussion

Figure 2 shows the maximum delamination-fretting wear finite element outcome in term of number of cycle effect under different stress ratio. The increasing trend in maximum delamination-fretting wear is noted when number of cycle increases. Similarly, the outcome of the maximum delamination-fretting wear results subjected to different mechanical and tribological properties of HAp-Ti-6Al-4V interface from FE analysis is captured as data points to formulate fast and novel failure prediction tool using multiple linear regression analysis. Multiple linear regression model is chosen to be sufficient to formulate failure predictive equation as a linear relationship between the dependent variable (maximum delamination-fretting wear depth) and the independent variables (delamination length, normal loading, fatigue loading, bone elastic modulus, stress ratio and cycle number) is registered based on FE results.

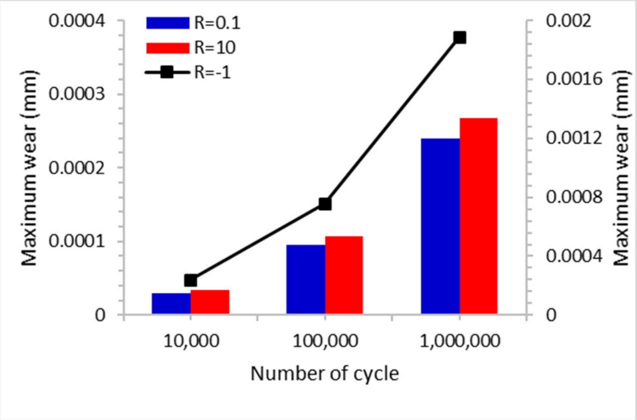

Fig. 2. Effect of cycle number on maximum wear depth under different stress ratio

3.1. Multiple linear regression model of stress ratio, R = 0.1

Table 1 presents multiple regression analysis output for stress ratio, R = 0.1 condition. Seventeen (17) sets of data are utilised to formulate maximum delamination-fretting wear depth prediction model for stress ratio, R = 0.1 condition. The resulting multiple linear regression equation for tensile-tensile (R = 0.1) condition is shown in Eq. 2 below:

$$Y=(-3.53005 \text{ x } 10^{-4}) + (6.90156 \text{ x } 10^{-5})x_1 + (\text{-}3.47320 \text{ x } 10^{-6})x_2 + (1.48643 \text{ x } 10^{-6})x_3 + (3.77302 \text{ x } 10^{-6})x_4 + (1.84889 \text{ x } 10^{-10})x_5 \qquad (2)$$

where, Y is maximum delamination-fretting wear depth, x_1 is delamination length, x_2 is normal loading, x_3 is fatigue loading range, x_4 is bone elastic modulus and x_5 is cycle number. It is apparent from data that the formulated maximum delamination-fretting wear depth predictive model for stress ratio, R = 0.1 condition displays a strong correlation between dependent and independent variables. This is reflected by Multiple R (correlation coefficient), R Square (coefficient of determination) and Adjusted R square values which near to value 1 indicating a strong positive relationship. In fact, R Square value 0.97 demonstrating goodness of fit with lower variation proportion of dependent variable that predicted from set of independent variables in multiple linear regression. In addition, the smaller value of standard error which is equivalent to $1.51 \text{ x } 10^{-5}$ represents great certainty of formulated predictive equation.

The Significance F value of $9.82 \text{ x } 10^{-8}$ (less than (0.05)) indicates higher reliability (statistically significant) of predicted results using formulated regression equation for present condition. Besides that, P-value lesser than 0.05 specifies the significance of an independent variable on maximum delamination-fretting wear depth prediction. The most significant variable that dictating maximum delamination-fretting wear depth is cycle number followed by bone elastic modulus, fatigue loading range and delamination length, meanwhile normal loading (higher than 0.05) is considered as least significant independent variable.

3.2. Multiple linear regression model of stress ratio, R = 10

Table 2 shows multiple regression analysis output for stress ratio, R = 10 condition. The multiple linear regression equation is formulated from seventeen (17) sets of data. The resulting multiple linear regression equation for compressive-compressive (R = 10) condition is given as Eq. 3 below:

$$Y=(-3.36745 \text{ x } 10^{-4}) + (7.02241 \text{ x } 10^{-5})x_1 + (\text{-}4.16800 \text{ x } 10^{-6})x_2 + (1.49356 \text{ x } 10^{-6})x_3 + (3.93090 \text{ x } 10^{-6})x_4 + (2.08678 \text{ x } 10^{-10})x_5 \qquad (3)$$

where, Y, x_1, x_2, x_3, x_4 and x_5 are maximum delamination-fretting wear depth, delamination length, normal loading, fatigue loading range, bone elastic modulus and cycle number respectively.

Table 1.
Multiple regression analysis output for stress ratio, R = 0.1

SUMMARY OUTPUT (R = 0.1)

Regression Statistics	
Multiple R	0.983083381
R Square	0.966452934
Adjusted R Square	0.951204268
Standard Error	1.51164E-05
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	7.24133E-08	1.44827E-08	63.37950571	9.81565E-08
Residual	11	2.51358E-09	2.28507E-10		
Total	16	7.49269E-08			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-3.53005E-04	0.000131844	-2.677434472	0.021506526
Delamination	6.90156E-05	1.84712E-05	3.736390588	0.003286738
Normal loading	-3.47320E-06	2.13779E-06	-1.624669583	0.132515245
Fatigue loading range	1.48643E-06	3.54048E-07	4.198381978	0.001489642
Bone elastic modulus	3.77302E-06	7.80512E-07	4.834024851	0.000523979
Cycle number	1.84889E-10	1.24853E-11	14.80856041	1.30456E-08

Table 2.
Multiple regression analysis output for stress ratio, R = 10

SUMMARY OUTPUT (R=10)

Regression Statistics	
Multiple R	0.98275152
R Square	0.96580055
Adjusted R Square	0.950255345
Standard Error	1.68765E-05
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	8.84759E-08	1.76952E-08	62.12851915	1.09032E-07
Residual	11	3.13297E-09	2.84816E-10		
Total	16	9.16089E-08			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-3.36745E-04	0.000147195	-2.2877438	0.042947689
Delamination	7.02241E-05	2.06218E-05	3.405331572	0.005873498
Normal loading	-4.16800E-06	2.3867E-06	-1.746347276	0.108577029
Fatigue loading range	1.49356E-06	3.95271E-07	3.778580506	0.003054586
Bone elastic modulus	3.93090E-06	8.71389E-07	4.511067928	0.000884944
Cycle number	2.08678E-10	1.3939E-11	14.97076663	1.1633E-08

The outcome quite revealing that a strong correlation between dependent (maximum delamination-fretting wear depth) variable and independent variables (delamination length, normal loading, fatigue loading range, bone elastic modulus and cycle number) as strong positive relation (near to 1) shown by Multiple R (correlation coefficient), R Square (coefficient of determination) and Adjusted R square values.

The multiple regression output provide evidence that goodness of fit is achieved due to R Square value is equivalent to 0.97 and lower standard error of 1.68×10^{-5}. Besides that, Significance F value of 1.09×10^{-7} proves the formulated predictive equation is statistically significant with higher reliability as less than 0.05. The most significant independent variable dominating maximum delamination-fretting wear depth for stress ratio, R = 10 (compressive-compressive) condition is number of cycles followed by bone elastic modulus, fatigue loading range and delamination length. Whereas, normal loading is least significant independent variable as P-value is higher than 0.05.

3.3. Multiple linear regression model of stress ratio, R = -1

Table 3 exhibits multiple regression analysis output for stress ratio, R = -1 condition. Seventeen (17) data sets are employed to formulate multiple linear regression equation to predict maximum delamination-fretting wear depth. The formulated multiple linear regression equation for tensile-compressive R = -1 condition is represented as in equation Eq. 4 below:

$$Y=(4.82782 \text{ x } 10^{-4}) + (-1.60705 \text{ x } 10^{-4})x_1 + (-2.19460 \text{ x } 10^{-5})x_2 + (8.56655 \text{ x } 10^{-7})x_3 + (2.75312 \text{ x } 10^{-5})x_4 + (1.10067 \text{ x } 10^{-9})x_5 \qquad (4)$$

where, Y is maximum delamination-fretting wear depth, x_1 is delamination length, x_2 is normal loading, x_3 is fatigue loading range, x_4 is bone elastic modulus and x_5 is cycle number. Multiple R (correlation coefficient), R Square (coefficient of determination) and Adjusted R square values indicating a good agreement between dependent and independent variables. The minimal variation between predicted and observed outcome is registered due to R Square value of 0.72 and lower standard error of 2.98×10^{-4} indicating acceptable goodness of fit.

In addition, formulated predictive equation for tensile-compressive (R = -1) condition is statistically significant with acceptable reliability with Significance F value of 0.0078 which is lower than 0.05. The most significant single variable influencing maximum delamination-fretting wear depth is cycle number with P-value lower than 0.05.

Table 3.
Multiple regression analysis output for stress ratio, R = -1

SUMMARY OUTPUT (R=-1)

Regression Statistics	
Multiple R	0.849237888
R Square	0.72120499
Adjusted R Square	0.594479985
Standard Error	0.000297608
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	2.52031E-06	5.04063E-07	5.691102497	0.00782956
Residual	11	9.74274E-07	8.85703E-08		
Total	16	3.49459E-06			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	4.82782E-04	0.002595708	0.18599244	0.855836162
Delamination	-1.60705E-04	0.000363655	-0.441917721	0.667110858
Normal loading	-2.19460E-05	4.20881E-05	-0.521430282	0.612403806
Fatigue loading range	8.56655E-07	3.13667E-06	0.273109443	0.789828505
Bone elastic modulus	2.75312E-05	1.53665E-05	1.791639425	0.100710237
Cycle number	1.10067E-09	2.45807E-10	4.477806047	0.000934778

Meanwhile, other additional independent variables are less significant which can be arranged by bone elastic modulus, normal loading, delamination length and fatigue loading in ascending order (towards least significant).

3.4. Multiple linear regression model of combined stress ratio

Additional multiple linear regression analysis is performed with the goal to cater all stress ratio condition in one formulated single predictive equation. Table 4 presents multiple regression analysis output for combined stress ratio, R = 0.1, 10 and -1 conditions respectively. The number of data sets are increased to fifty-one (51) to guarantee the robustness of formulated multiple linear regression equation to predict maximum delamination-fretting wear depth. An additional independent variable which is stress ratio is added with other variables as discussed previously in formulating single stress ratio predictive equations. The resulting multiple linear regression equation for combined stress ratio condition is presented in Eq. 5 below:

$$Y=(-1.39348 \text{ x } 10^{-3}) + (1.83023 \text{ x } 10^{-5})x_1 + (5.06717 \text{ x } 10^{-6})x_2 + (3.77523 \text{ x } 10^{-6})x_3 + (1.83526 \text{ x } 10^{-6})x_4 + (1.06388 \text{ x } 10^{-5})x_5 + (5.15551 \text{ x } 10^{-10})x_6 \tag{5}$$

where, Y, x_1, x_2, x_3, x_4, x_5 and x_6 are maximum delamination-fretting wear depth, delamination length, normal loading, fatigue loading range, stress ratio, bone elastic modulus and cycle number respectively. The data highlights that formulated predictive equation using multiple linear regression model for combined stress ratio cases suggesting a strong correlation between dependent variable (maximum delamination-fretting wear depth) and independent variables (delamination length, normal loading, fatigue loading range, stress ratio, bone elastic modulus and cycle number).

The result is in line with Multiple R (correlation coefficient), R Square (coefficient of determination) and Adjusted R square values which near to value 1 demonstrating a strong positive relationship. In addition, R Square value of 0.89 and standard error equivalent to 2.26 x 10^{-4} indicating strong goodness of fit and certainty of predictive equation.

The outcome also revealed that formulated multivariable linear regression model is highly reliable and statistically significant as Significance F value of 1.57 x 10^{-19} which corresponding to less than 0.05. Furthermore, the most

Table 4.
Multiple regression analysis output for combined stress ratio, R = 0.1, 10 and -1

SUMMARY OUTPUT (combined R)

Regression Statistics	
Multiple R	0.943758392
R Square	0.890679903
Adjusted R Square	0.875772617
Standard Error	0.000225968
Observations	51

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	1.8305E-05	3.05084E-06	59.74795832	1.57176E-19
Residual	44	2.24672E-06	5.10618E-08		
Total	50	2.05517E-05			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1.39348E-03	0.000344994	-4.039141721	0.000211695
Delamination	1.83023E-05	0.000158032	0.115813986	0.90832693
Normal loading	5.06717E-06	1.37567E-05	0.368341936	0.714384576
Fatigue loading range	3.77523E-06	2.51647E-07	15.00208705	6.51447E-19
Stress ratio	1.83526E-06	7.80569E-06	0.235118254	0.815207782
Bone elastic modulus	1.06388E-05	6.67434E-06	1.593977955	0.118100081
Cycle number	5.15551E-10	1.0679E-10	4.827712661	1.69962E-05

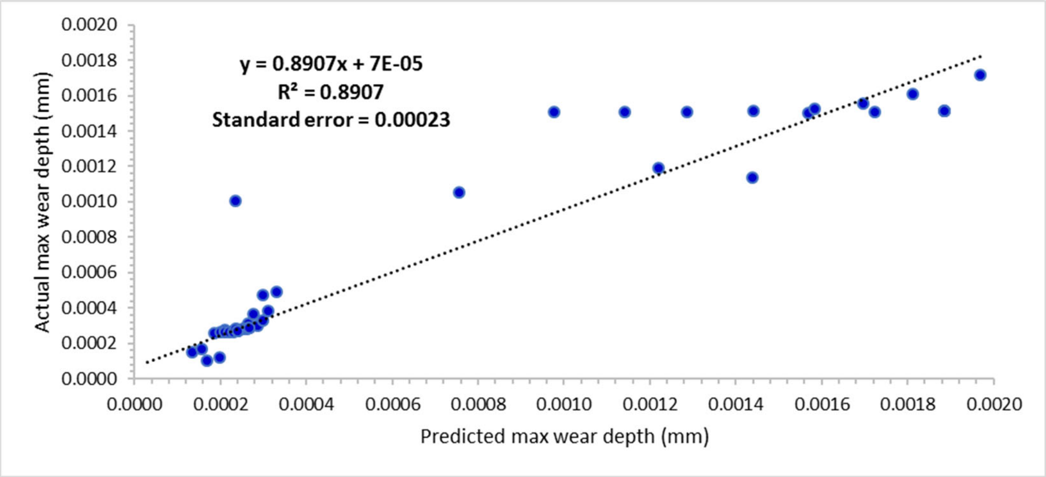

Fig. 3. Actual versus predicted max wear depth scattered plot

striking result emerge from data is that fatigue loading range followed by cycle number independent variables significantly dictating maximum delamination-fretting wear depth prediction with P-value lesser than 0.05.

Meanwhile, bone elastic modulus, normal loading, stress ratio and delamination length are least significant independent variables (P-value lesser than 0.05) in ascending order. It is apparent that formulated predictive equation using multivariable linear regression model can be adopted as a failure prediction tool for fast prediction of maximum delamination-fretting wear depth at HAp-Ti-6Al-4V interface of artificial femoral stem component in total hip replacement.

3.5. Formulated predictive equation validation

The validation of formulated predictive Eq. 5 is performed by comparing actual maximum wear depth with predicted maximum wear depth. Figure 3 presents actual versus predicted max wear depth scattered plot. A trendline is created based on the scattered plot to establish the relationship between actual and predicted values. The scattered plot is quite revealing that good agreement is achieved between actual and predicted values as R Square value of 0.8907 is registered. R Square value closer to 1 indicates strong correlation and goodness of fit with less foggy or dispersed points from trendline [21-24]. In addition, it is apparent from the data that registered standard is 0.00023. The minimal standard error defines the robustness of the formulated predictive equation. Thus, the validation of formulated predictive equation as a fast and novel failure prediction tool is successfully achieved.

4. Conclusions

This study is set to formulate delamination-fretting wear failure predictive equation in HAp-Ti-6Al-4V interface of hip arthroplasty femoral stem component using multiple linear regression analysis. The following conclusion can be drawn from the attempted research:

Maximum delamination-fretting wear predictive equations are successfully formulated using multiple linear regression analysis subjected to four condition, i.e., R = 0.1, R = 10, R =-1 and combined stress ratio.

The formulated predictive equations displaying a strong correlation between dependent and independent variables with R Square (coefficient of determination) near to 1 which guarantees goodness of fit.

Highly reliable and statistically significant predictive equations is adopted as fast maximum delamination-fretting wear failure prediction tool at HAp-Ti-6Al-4V interface of hip arthroplasty.

Acknowledgements

Author acknowledges present research work is supported by Taylor's University Lakeside Campus, UOW Malaysia KDU University College, Universiti Tun Hussein Onn Malaysia, Nagaoka Univesity of Technology, Japan, Ministry of Education Malaysia and Japan Science and Technology Agency (JST).

Additional information

The article was presented at the 5th ICET 2021: 5th International Conference on Engineering Technology Virtual Conference KEMAMAN, Malaysia, October 25-26, 2021.

References

[1] Y. Otsuka, Y. Miyashita, Y. Mutoh, Effects of delamination on fretting wear behaviors of plasma-sprayed hydroxyapatite coating, Mechanical Engineering Journal 3/2 (2016) 15-00573. DOI: https://doi.org/10.1299/mej.15-00573

[2] S.E. Graves, D. Davidson, L. Ingerson, P. Ryan, E.C. Griffith, B.F. McDermott, N.L. Pratt, The Australian orthopaedic association national joint replacement registry, Medical Journal of Australia 180/5S (2004) S31-S34. DOI: https://doi.org/10.5694/j.1326-5377.2004.tb05911.x

[3] Australian Orthopaedic Association National Joint Replacement Registry: Automated Industry Reporting System, Adelaide, 2019.

[4] W.A. Siswanto, M. Nagentrau, A.M. Tobi, M.N. Tamin, Prediction of plastic deformation under contact condition by quasi-static and dynamic simulations using explicit finite element analysis, Journal of Mechanical Science and Technology 30/11 (2016) 5093-5101. DOI: https://doi.org/10.1007/s12206-016-1027-3

[5] M. Nagentrau, W.A. Siswanto, M. Tobi, A. Latif, Predicting the sliding amplitude of plastic deformation in the reciprocating sliding contact, ARPN Journal of Engineering and Applied Sciences 11/4 (2016) 2266-2271.

[6] Y. Otsuka, H. Kawaguchi, Y. Mutoh, Cyclic delamination behavior of plasma-sprayed hydroxyapatite coating on Ti-6Al-4V substrates in simulated body fluid, Materials Science and Engineering: C 67 (2016) 533-541. DOI: https://doi.org/10.1016/j.msec.2016.05.058

[7] Y. Otsuka, D. Kojima, Y. Mutoh, Prediction of cyclic delamination lives of plasma-sprayed hydroxyapatite coating on Ti–6Al–4V substrates with considering wear and dissolutions, Journal of the Mechanical Behavior of Biomedical Materials 64 (2016) 113-124. DOI: https://doi.org/10.1016/j.jmbbm.2016.07.026

[8] M. Nagentrau, A.L.M. Tobi, S. Jamian, Y. Otsuka, Contact slip prediction in HAp coated artificial hip implant using finite element analysis, Mechanical Engineering Journal 6/3 (2019) 18-00562. DOI: https://doi.org/10.1299/mej.18-00562

[9] M. Nagentrau, A.L.M. Tobi, S. Jamian, Y. Otsuka, HAp Coated Hip Prosthesis Contact Pressure Prediction Using FEM Analysis, Materials Science Forum 991 (2020) 53-61. DOI: https://doi.org/10.4028/www.scientific.net/MSF.991.53

[10] M. Nagentrau, A.L.M. Tobi, S. Jamian, Y. Otsuka, R. Hussin, Delamination-fretting wear failure evaluation at HAp-Ti-6Al–4V interface of uncemented artificial hip implant, Journal of the Mechanical Behavior of Biomedical Materials 122 (2021) 104657. DOI: https://doi.org/10.1016/j.jmbbm.2021.104657

[11] K. Fallahnezhad, R.H. Oskouei, H. Badnava, M. Taylor, The influence of assembly force on the material loss at the metallic head-neck junction of hip implants subjected to cyclic fretting wear, Metals 9/4 2019 422. DOI: https://doi.org/10.3390/met9040422

[12] T. Bitter, I. Khan, T. Marriott, E. Lovelady, N. Verdonschot, D. Janssen, Finite element wear prediction using adaptive meshing at the modular taper interface of hip implants, Journal of the Mechanical Behavior of Biomedical Materials 77 (2018) 616-623. DOI: https://doi.org/10.1016/j.jmbbm.2017.10.032

[13] A. Chakraborty, D. Goswami, Prediction of slope stability using multiple linear regression (MLR) and artificial neural network (ANN), Arabian Journal of Geosciences 10/17 (2017) 385. DOI: https://doi.org/10.1007/s12517-017-3167-x

[14] I. Yılmaz, A.G. Yuksek, An example of artificial neural network (ANN) application for indirect estimation of rock parameters, Rock Mechanics and Rock Engineering 41/5 (2008) 781-795. DOI: https://doi.org/10.1007/s00603-007-0138-7

[15] B. Pradhan, Remote sensing and GIS-based landslide hazard analysis and cross-validation using multivariate logistic regression model on three test areas in Malaysia, Advances in Space Research 45/10 (2010) 1244-1256. DOI: https://doi.org/10.1016/j.asr.2010.01.006

[16] P. Boye, The Use of Multiple Linear Regressions in Determining the Relationship between Housing Unit Price and Some Major Components in a Real Estate Building, Scottish Journal of Arts, Social Sciences, and Scientific Studies 7 (2012) 3-17.

[17] C. Petroutsatou, S. Lambropoulos, J.P. Pantouvakis, Road tunnel early cost estimates using multiple regression analysis, Operational Research 6/3 (2006) 311-322. DOI: https://doi.org/10.1007/BF02941259

[18] P. Surajit, G. Kumar, Multi-response optimization using multiple regression-based weighted signal-to-

noise ratio, Quality Engineering 22/4 (2010) 336-350. DOI: https://doi.org/10.1080/08982112.2010.495368

[19] B.P. Chang, H.M. Akil, R.B. Nasir, A. Khan, Optimization on wear performance of UHMWPE composites using response surface methodology, Tribology International 88 (2015) 252-262. DOI: https://doi.org/10.1016/j.triboint.2015.03.028

[20] T. Catalina, V. Iordache, B. Caracaleanu, Multiple regression model for fast prediction of the heating energy demand, Energy and Buildings 57 (2013) 302-312. DOI: https://doi.org/10.1016/j.enbuild.2012.11.010

[21] H. Singh, R. Garg, Effects of process parameters on material removal rate in WEDM, Journal of Achievements in Materials and Manufacturing Engineering 32/1 (2009) 70-74.

[22] P. Šimeček, D. Hajduk, Prediction of mechanical properties of hot rolled steel products, Journal of Achievements in Materials and Manufacturing Engineering 20/1-2 (2007) 395-398.

[23] B. Smoljan, D. Iljkić, N. Tomašić, Computer simulation of mechanical properties of quenched and tempered steel specimen, Journal of Achievements in Materials and Manufacturing Engineering 40/2 (2010) 155-159.

[24] S. Delijaicov, A T. Fleury, F.P.R. Martins, Application of multiple regression and neural networks to synthesize a model for peen forming process planning, Journal of Achievements in Materials and Manufacturing Engineering 43/2 (2010) 651-656.