The International Journal of Engineering and Science (IJES)
|| Volume || 14 || Issue || 2 || Pages || PP 10-21 || 2025 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Enhancing Cladding Fastener Performance through Geometry Optimization for Maximum Pull-Out Force

Vahid Hassani[1], Zunaidi Ibrahim[2], Adrian Morris[3], Roger O'Brien[3], Hamid Abbasi[1], Roohollah Barzamini

[1]*City St George's, University of London, Centre for Compressor Technology, Department of Engineering, School of Science and Technology, London EC1V 0HB, United Kingdom*
[2]*Department of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Brunei, Tunku Highway, Gadong BE1410, Brunei Darussalam*
[3]*School of Engineering, Faculty of Technology, The University of Sunderland, St Peter's Campus, Sunderland, SR6 0DD, United Kingdom*

--***ABSTRACT***--
In recent years, there has been increasing interest in roof cladding systems due to their wide applications in the construction of low-rise buildings. Previous studies highlight the importance of analyzing these systems for the design of fasteners with improved structural performance, particularly against damage and failure caused by high wind events at the connection between the fastener and purlin sheet. To address the need for enhancing the pull-out force capacity of cladding fasteners, this paper presents three methods for geometry optimization of a high-strength steel fastener (austenitic 316). The first method employs a genetic algorithm to optimize two key parameters, thread depth and thread angle, to minimize the maximum von Mises stress under tensile loading. The second method involves sweeping these parameters to generate data for training a neural network, which then predicts the optimal geometry based on a desired von Mises stress. The third method proposes a mathematical model to estimate the pull-out force capacity and uses it to determine the optimal geometry by maximizing this capacity. Finally, tensile tests are conducted to compare the pull-out force capacities of the fasteners designed by each method.

Date of Submission: 27-02-2025 Date of acceptance: 16-03-2025

I. Introduction

Hurricane, cyclones and storms are classified as high wind events that can cause destructive effects to the roof cladding systems. The damage might not only be restricted to the roof cladding system, but also it might involve the entire building and cause irreparable failures. Therefore, the structural investigation of the roof cladding systems is quint essential from two aspects, i.e., cladding system failure and cladding fasteners failure. The former one is considered as a major damage in the system, while the later one is considered as a minor damage that can potentially cause a progressive collapse of the entire cladding system.

From a load application perspective, roof cladding systems can be analysed in terms of static or dynamic loading. Significant efforts in the literature have focused on analysing static and dynamic failures in these systems. For instance, localized pull-out failures, a critical failure type, have received much attention due to their potential to initiate extensive system-wide damage, especially under high wind uplift loads. Some studies have demonstrated that localized pull-out failures can lead to major system failures [1, 2]. Additionally, the prediction of pull-out force capacity has been a focus of research. For example, a mathematical model developed in [3] improved the accuracy of predicted pull-out force by considering sheet thickness and cladding fastener geometry as key parameters. In a similar study, the key parameters were selected as sheet thickness, ultimate tensile strength, and fastener head diameter, yielding better pull-out force predictions compared to experimental results [4]. Another study investigated the shear behaviour of fasteners, formulating the monotonic and cyclic behaviour of connections [5], while the effect of fastener location on the shear behaviour of roofing systems was also analysed [6]. Finite element analysis (FEA) has been used as a valuable tool for examining the effects of material properties and geometric parameters of cladding systems and fasteners under high wind conditions [7].

Various approaches have been proposed to model the dynamic behaviour of cladding systems under dynamic loads. For example, wind loading correlation and wind directionality effects are critical factors that must be addressed as part of a robust damage estimation framework for such structures [8]. Similar studies have examined the pressure distribution generated by wind on steel roofing systems [9-14].

Fatigue is a significant factor contributing to failures in roof cladding systems. Several studies have focused on the impact of wind on the fatigue behaviour of roof cladding, including those by Kumar [15], Kumar and Stathopoulos [16], and Jan Cous et al. [17]. Additionally, in a different approach, the results of static and cyclic wind uplift tests were combined to ensure the safe design of roof cladding systems against fluctuating wind uplift pressure [18,19].

An experimental study addressed a damage estimation model for steel roofing systems using wind tunnel data [20]. A test procedure was developed to simulate the fluctuating pressures of a cyclone on sections of roof cladding by utilizing a pressure loading actuator (PLA) [21]. This method effectively replicates cladding failures observed after severe cyclones.

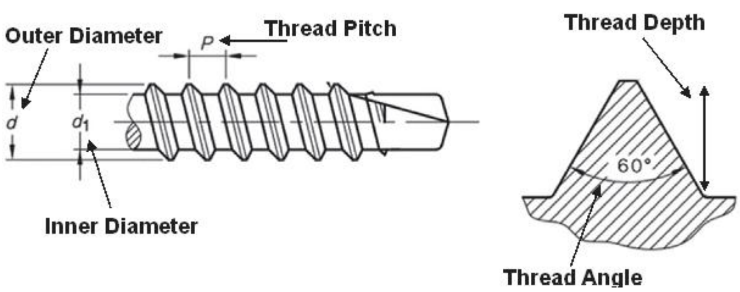
In recent years, various shape, topology, and material optimization techniques have been proposed to enhance the mechanical properties of civil structures and components [22-26]. Building on previous research, this paper presents three optimization methods for the geometry of a typical cladding fastener to improve its pull-out force capacity. These methods—genetic algorithm-based, data-driven method, and mathematical model-based—utilize CAD software to initiate the fastener design with initial values of thread depth and angle as optimization parameters. The first two methods offer heuristic optimization approaches, while the third is based on an approximate hypothesis to estimate the maximum pull-out force, depending on the fastener geometry and the sheet involved. The performance of each method is evaluated through functional tensile tests, demonstrating the potential of geometry optimization techniques for roof cladding solutions.

The remainder of the paper is organized as follows: Sections 2, 3, and 4 discuss the genetic algorithm-based method, data-driven method, and mathematical model-based method, respectively. Section 5 outlines the experimental setup and compares the three fasteners designed by these methods in terms of maximum pull-out force. The paper concludes with final remarks in Section 6.

II. Genetic Algorithm Based Method

This section outlines the process of designing the cladding fastener in three steps using the genetic algorithm (GA). First, the initial geometry of the fastener is depicted in Figure 1a-b. As demonstrated, the fastener's geometry consists of five sections that collectively make up its overall configuration. These sections namely, outer diameter, *d*, inner diameter, d_1, pitch, *P*, thread depth and thread angle are shown in Figure 1b.

a)



b)

Figure 1. a) The Candid Cladding Fastener in this Study, b) Main Parameters of Cladding Fastener.

The optimization method is implemented using interfaces among three software packages, namely Solidworks, MATLAB and COMSOL as shown in Figure 2.

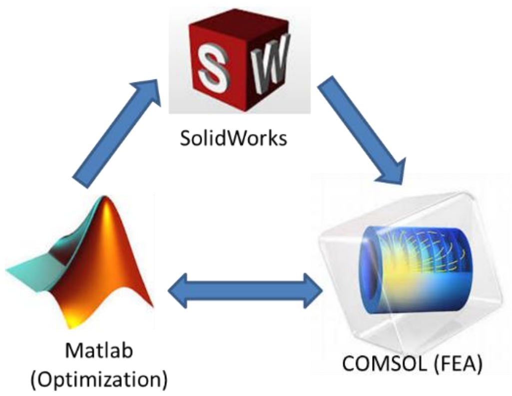


Figure 2. Digital Workflow/Livelink between Three Software Packages.

The digital workflow among these software packages begins with sketching the fastener in Solidworks, followed by exporting it to COMSOL for finite element analysis (FEA). Subsequently, optimization is carried out in MATLAB, and the geometry parameters are updated in Solidworks, all in a closed-loop manner, as illustrated in Figure 2.

As mentioned earlier, the design process starts with sketching the initial configuration of the fastener, which is based on its geometry parameters, including inner and outer diameters, pitch, thread depth and angle, and the drill section diameter, which is not considered in this research. The goal of the fastener design is to ensure a high pull-out force capacity in practice when subjected to significant wind loads. To the author's knowledge, the most critical parameters that facilitate contact and engagement with the cladding sheets, purlin, and batten are the thread depth, thread angle, and pitch. In this research, the thread pitch is assumed to be fixed to simplify manufacturing and reduce computational time during the structural optimization process. The only parameters selected for design and geometry optimization are the thread depth and angle.

In this study, the thickness of the sheet is chosen 1.6 mm and the pitch of the fastener remains constant i.e. 1.82 mm. Using these assumptions, the parameters that might affect the final value of pull-out force capacity are the thread depth and angle that are shown in Figure 1a-b.

After choosing the optimization variables, the geometry optimization problem can be defined as the minimization of a real objective function, *f*, which is a dependent function to the fastener parameters and is subjected to some constraints. The general form of the optimization problem is given as:

$$\begin{aligned} &\text{Min} && f(x) \\ &\text{Subject to} && g_j(x) \leq 0,\ j=1,m \\ &&& h_k(x) = 0, k = 1, l \\ &&& x_i^l \leq x_i \leq x_i^u, i = 1, n \end{aligned} \quad (1)$$

where $x = [x_1, ..., x_n]$ is the vector of design parameters, $f(x)$ is the objective function, $g_j(x)$ are the inequality constraints, $h_k(x)$ are the equality constraints and x_i^l and x_i^u are lower and upper bounds of the i^{th} design variables, respectively.

In this section, maximum von-Mises stress is selected as the objective function without any constraint. For further understanding the optimization problem, the generic form of equation is rewritten as shown in Table 1.

Table 1. Formulation of Optimization Problem.

Given	Boundary Conditions (B.C), Loads, Material
Find	D_i: The i^{th} parameter of the cladding fastener that are the thread depth and angle.
Satisfy	$D_i^l \leq D_i \leq D_i^u$: Lower and upper bounds of the parameters.
Minimize	Max σ_{von_Mises} : Maximum von Mises Stress

Given the boundary conditions, B.C., loads, and material information, the thread depth and angle, D_is, will be optimized during the geometry optimization process. In this research, the static characteristic of von-Mises stress is calculated for the fastener assembled with the relevant cladding sheet. By setting the initial values of the design parameters, D_is, to the original fastener's design parameters, an analysis was conducted using COMSOL software as the FEA tool. It is important to note that the upper bounds of the parameters were chosen to ensure there is no interference between neighbouring threads, while the lower bounds were selected based on the limitations of manufacturing methods. In this study, the lower bounds for the parameters are set at 0.7 mm and 20° for the thread depth and angle, respectively, with upper bounds increased to 1.45 mm and 35°. The design parameters of the original fastener are 1.21 mm and 30° for the thread depth and angle.

A load is applied under the fastener's head, and its magnitude can be selected as any value within the elastic range of the fastener, specifically for geometry optimization purposes. The load magnitude for FEA is set at 500 N, as illustrated in Figure 3. Austenitic steel 316 is chosen as the material for both the fastener and the associated sheet, with its mechanical properties provided in Table 2. The cladding sheet is positioned 5 mm below the fastener's head because, in the actual setup, an upper plate, as shown in Figure 4, with a thickness of 5 mm is placed between the sheet and the lower surface of the fastener's head.

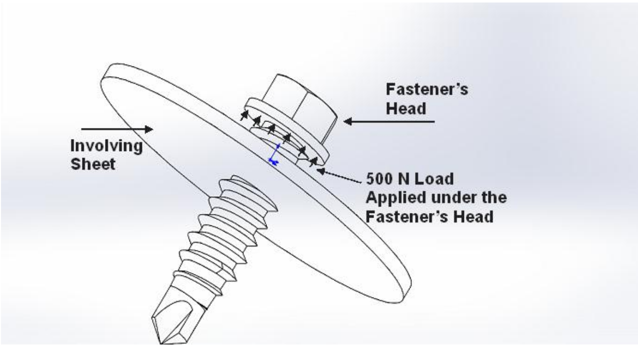


Figure 3. 500N Load Applied under the Fastener's Head.

To define the boundary conditions of the sheet-fastener assembly, the circumference of the involving sheet is assumed to be fixed with zero displacement and rotation in all directions. Figure 4 shows the application of boundary conditions to the circumference of the sheet.

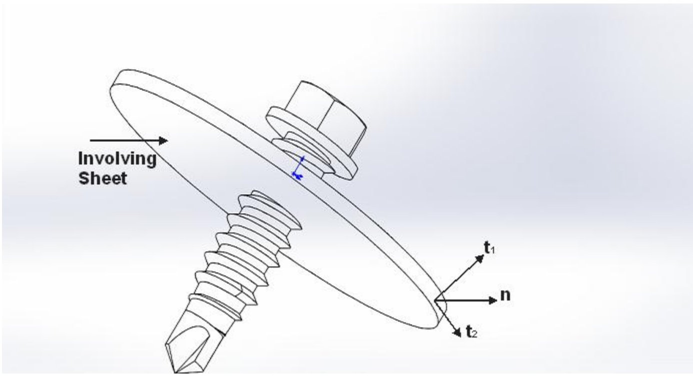


Figure 4. Zero Displacement along Tangential Directions, t_1 and t_2 and Normal Direction, n of the Circumference of the Involving Sheet.

Table 2. Mechanical Properties of Austenitic Steel 316

Mechanical Properties	Quantity
Young's Modulus	192 GPa
Yield Strength	137 MPa
Tensile Strength	550 MPa
Poisson's Ratio	0.3
Density	7800 kg/m^3

Figure 5 presents the results of the static analysis of the fastener-sheet assembly, where the von-Mises stress is measured at 146 MPa prior to geometry optimization. With the value from the pre-optimization analysis established, the optimized structure is displayed in Figure 6, featuring a thread depth of 1.4 mm and a thread angle of 30°. As shown in Figure 6, the maximum von-Mises stress value obtained is 120 MPa, representing a 15% reduction compared to the original configuration.

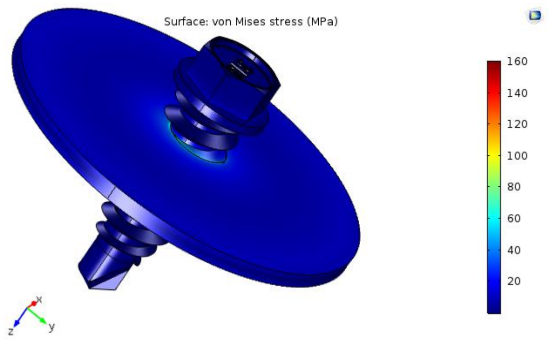


Figure 5. FEA before Geometry Optimization of the Fastener.

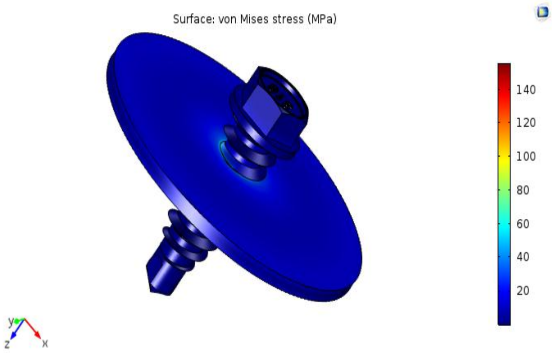


Figure 6. FEA after Geometry Optimization of the Fastener.

III. Data Driven Method

his section outlines the method for designing the cladding fastener in two steps using the parametric sweep approach and predictor neural network (PNN). Similar to the GA method, the initial geometry of the fastener is sketched in SolidWorks, as shown in Figure 1a-b. The two parameters, thread depth and angle, are set to their initial values defined at the start of the parametric sweep method. In a live link with COMSOL software, these parameters are assigned a range of values: 0.8 mm to 1.45 mm for the thread depth and 20° to 35° for the thread angle. The next step involves performing FEA in COMSOL in a combinatorial manner within the specified data range, where one value of the thread depth is paired with all values of the thread angle sequentially, allowing for the calculation of von-Mises stress for each pair of data. For instance, the thread depth is initially set to 0.8 mm and used with all thread angle values ranging from 20°, 21°, up to 35°. This procedure is repeated for a thread depth of 0.81 mm and all values of the thread angle in the subsequent sequence. The von-Mises stresses are calculated for all pairs, and the corresponding pre-calculated von-Mises stresses serve as input for the two-layer neural network (NN), while the thread depth and angle are designated as target outputs for NN training. This NN features one neuron in the input layer (pre-calculated von-Mises stresses), five neurons in the hidden layer, and two neurons in the output layer, representing the predicted design parameters, i.e., thread depth and angle. Figure 7 illustrates the architecture of the NN, while Figure 8 depicts the workflow of the parametric sweep method.

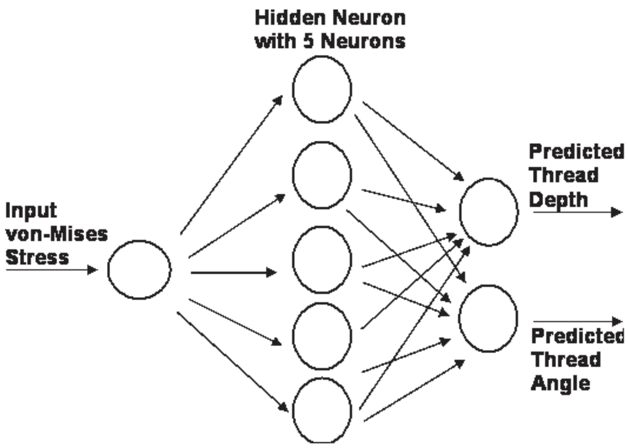


Figure 7. Predictive Neural Network (PNN) with Five Neurons at Hidden Layer.

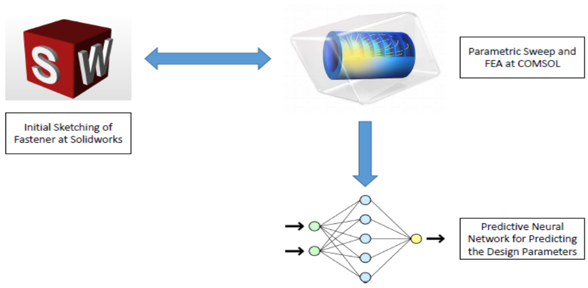
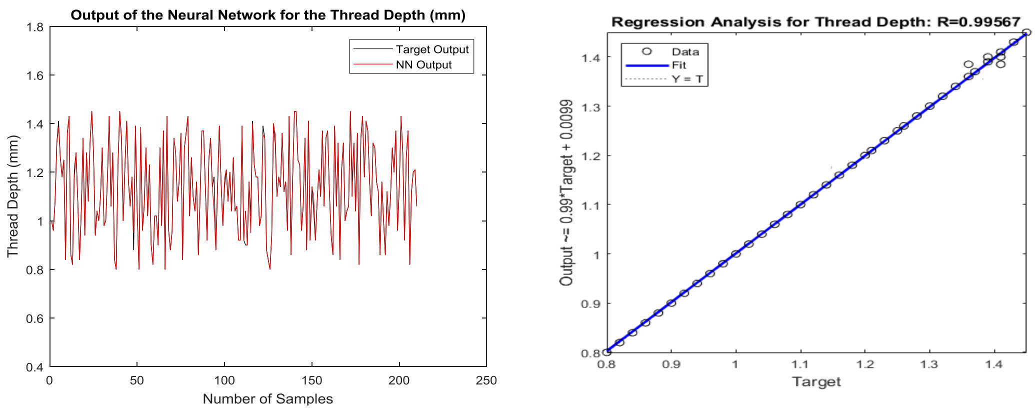
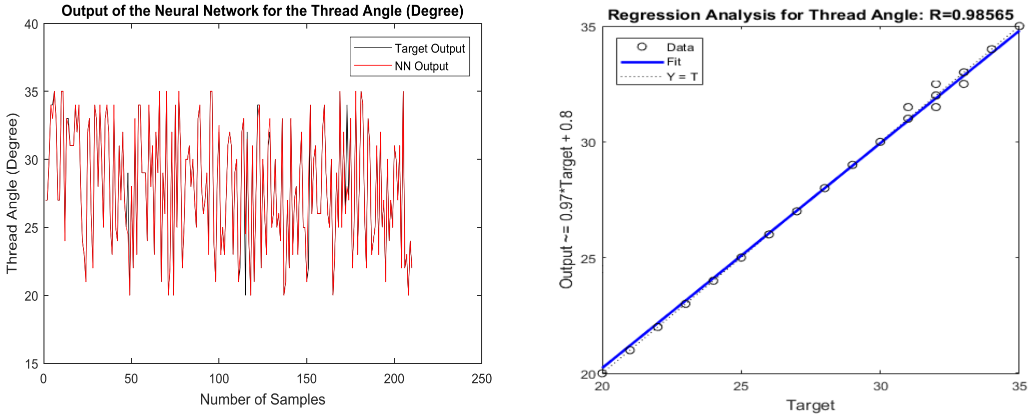


Figure 8. Workflow of the Parametric Sweep Method.

Upon completion of the neural network (NN) training, the specified desired von-Mises stress at the input of the predictor neural network (PNN) will yield two values of design parameters at its output. By conducting the parametric sweep analysis in COMSOL, one can determine the maximum and minimum values of the von-Mises stress. Any provided value of von-Mises stress inputted into the PNN will be interpolated or extrapolated based on whether it falls within the range of minimum and maximum values or beyond this range, respectively. For example, the minimum value obtained through the parametric sweep approach is 128 MPa. If we wish to estimate the design parameters for an input of 120 MPa to the PNN, the output will indicate 0.945 mm and 34° as the corresponding thread depth and angle. The results of the PNN training are illustrated in Figure 9.



a)



b)

Figure 9. a) Trained Data for the Thread Depth (Left) and its Corresponding Regression Analysis (Right), b) Trained Data for the Thread Angle (Left) and its Corresponding Regression Analysis (Right).

IV. Mathematical Model Based Method

As completely discussed in [27], a mathematical model was proposed as written in Equation (1) to estimate the maximum pull-out force of the high strength steel fasteners, P_u. This model has been obtained by modification of the former model proposed by Sivapathasundaram and Mahendran [3] that is represented in Equation (2). Prior to [3], the pull-out force capacity of the cold-formed steels used to be predicted by using the design Equation (3), as standardized by Eurocode 3 Part 1-3 (EN 1993-1-3, 2006) [28]. In all equations, t stands for the steel sheet thickness, P denotes the pitch value of the fastener which is chosen 1.82 mm in this study, d_{max} is external diameter which is 6.74 mm, f_u denotes the ultimate tensile strength of A653 low carbon mild steel that is approximately 550 MPa, d is chosen slightly larger than the internal diameter of the fastener, i.e. 5.3 mm and θ denotes the thread angle which is chosen 30º. For further study about how this mathematical model has been obtained, readers may refer to [27].

$$P_u = A(t)^B (d_{\max})^C f_u \left(\frac{(d_{\max} - d)}{P}\right)^D \left(\frac{t - (P - 2tg\theta(\frac{d_{\max} - d}{2}))}{2tg\theta(\frac{d_{\max} - d}{2})}\right)^E \quad (1)$$

$$P_u = 1.62 t^{1.3} d^{0.7} f_u \left[(d_{\max} - d)/P\right]^{0.3} \quad (2)$$

$$P_u = 0.65 t.d.f_u \quad (3)$$

The values A, B, C, D, and E were determined as A = 1.62, B = 1.35, C = 0.65, D = 1.1, and E = 0.06 for the proposed model. Following the acquisition of the model parameters represented in Equation (1), the thread depth and angle were chosen as optimization variables with specific lower and upper bounds discussed in Section 2. An optimization process was conducted using the genetic algorithm (GA) to identify the maximum pull-out force capacity. The maximum force capacity achieved was 5800 N at a thread depth of 1.45 mm and a thread angle of 35°. The corresponding von-Mises stress for this fastener under a load of 500 N was calculated to be 118 MPa.

V. Experimental Set-up and Results

To measure the strength of the connection or pull-out force capacity and validate the results obtained from the simulation, an experimental setup was established, as shown in Figures 10-14. As depicted in Figure 14, the Zwick Z010 tensile test machine was selected to apply tensile forces, with a maximum load capacity of up to 10 kN. Rectangular test plates were prepared using a laser cutting machine, featuring a thickness of 1.6 mm. The rectangular test sample is illustrated in Figure 10.

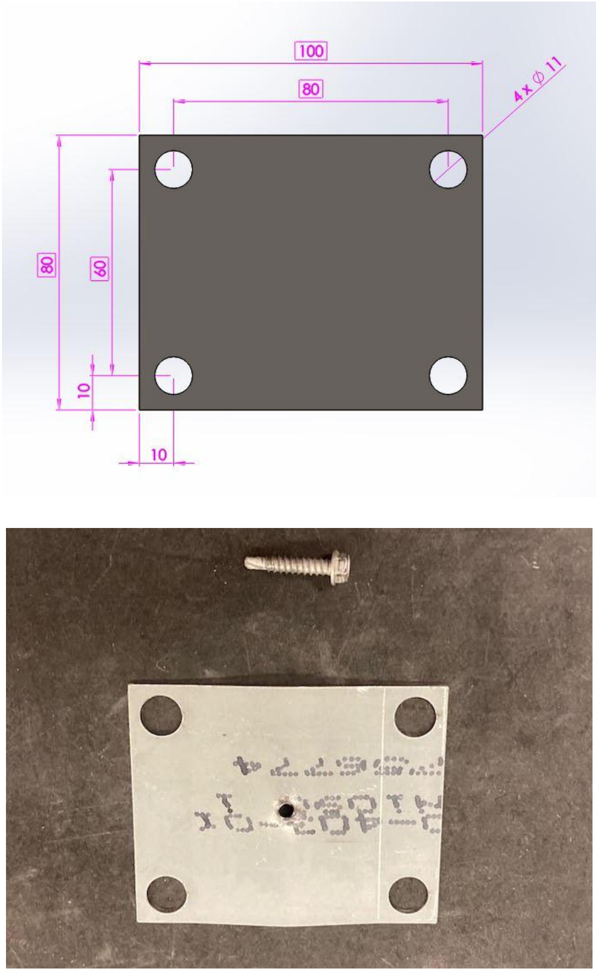


Figure 10. Rectangular Test Sample (Dimensions in mm)

The rectangular sample was secured in a fixture to be attached to the bottom jaw, as shown in Figure 11. The cladding fastener was subsequently drilled into and through the rectangular test sample using a Hilti Impact Driver (ST1800-A22).

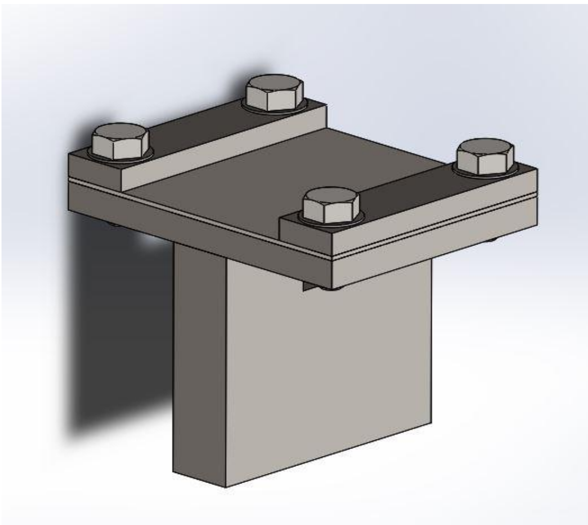


Figure 11. The Test Sample Bolted into the Bottom Jaw

Care must be taken to ensure that the fastener is drilled as close to the centre of the test sample as possible, using marks on the sample and calibrated spacers designed to hold the upper plate in the correct position. Afterward, the upper plate is bolted to the upper jaws of the Zwick Z010, as shown in Figures 12 and 13. The two halves of the tensile test machine are then pulled apart until the screwed joint fails.

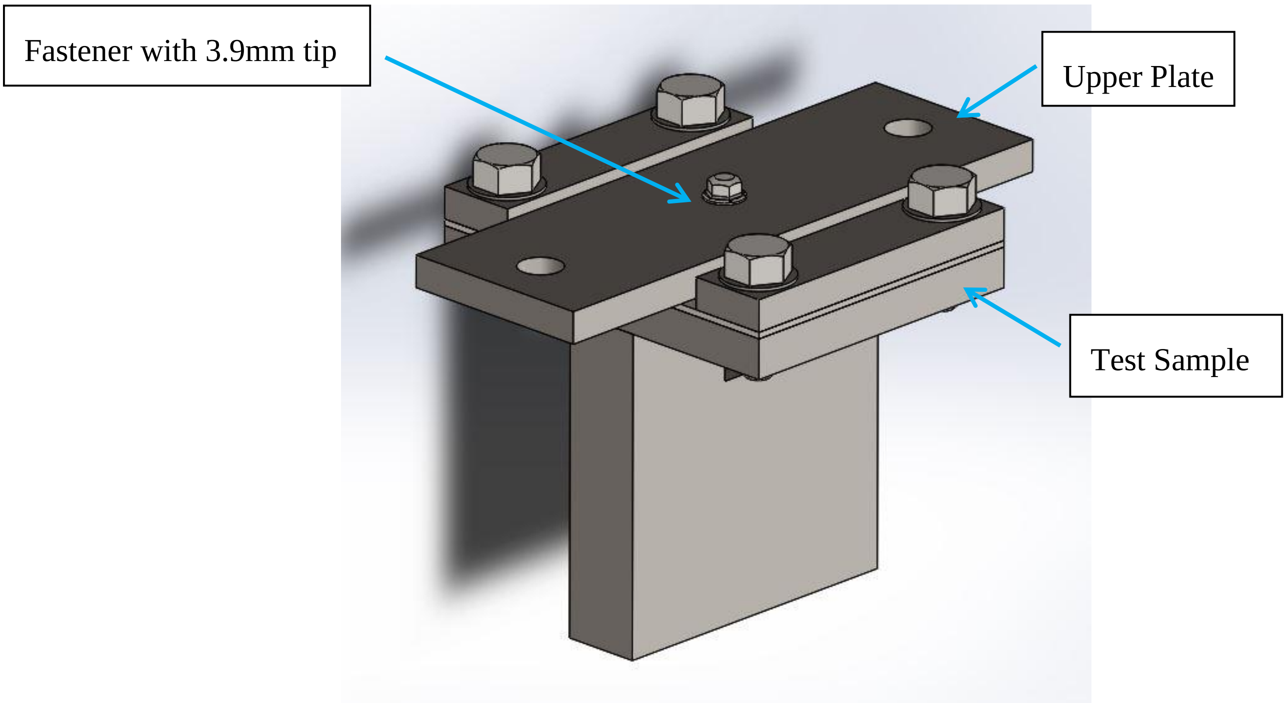


Figure 12. Upper Plate Attached by Cladding Fastener

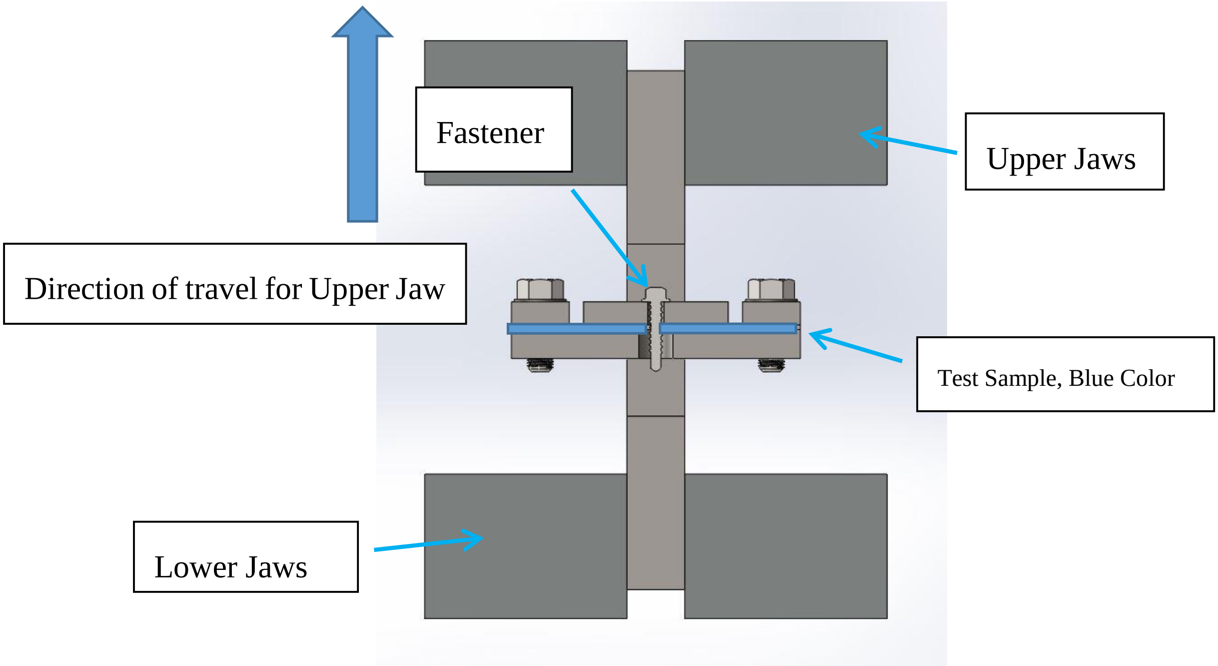


Figure 13. Schematic of Tensile Test Lower and Upper Jaws

To measure the pull-out force capacity of the fasteners and validate the simulation results, the original sample fasteners were tested. For each test, the maximum pull-out force capacity was recorded. Each test was repeated five times, and the average values were documented. The results are presented in Tables 3 and 4 and in Figure 16.

Figure 14. Zwick Z010 Tensile Test Machine with Capacity up to 10 Kn

Table 3: The Results of the Physical Experiments

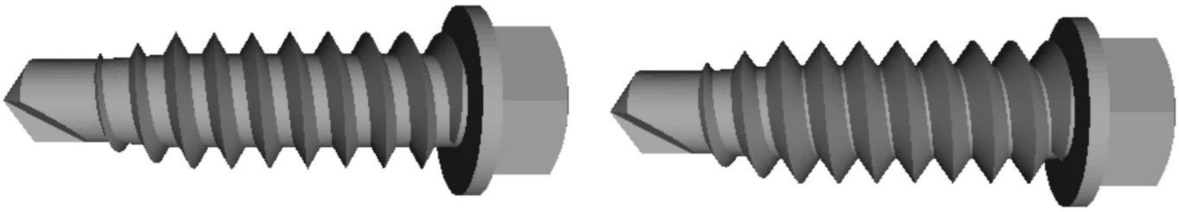
Thread Depth mm	***Thread Angle Degrees***	***Average pull out force N***
1.21mm (original fastener)	*30 degrees (original fastener)*	*4470*

Table 4. The Results of the Simulations

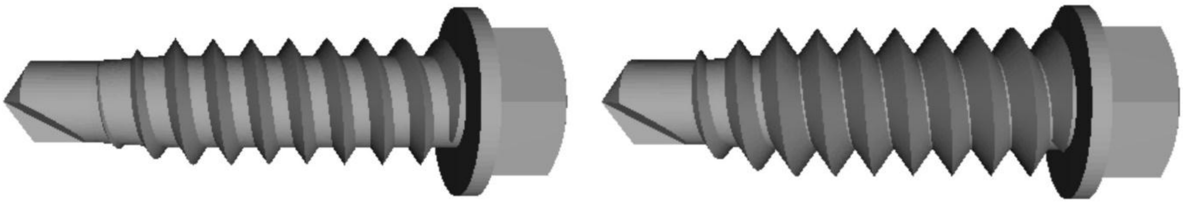
Thread Depth	***Thread Angle º***	***Pull-Out Force N***
1.4mm (GA Method)	*30º (GA Method)*	*4900*
0.945mm (Parametric Sweep Method)	*34º (Parametric Sweep Method)*	*4550*
1.45mm (Model-Based Method)	*35º (Model-Based Method)*	*5800*
1.21mm (Original Fastener)	*30º (Original Fastener)*	*4400*

Comparison with the experimental results reveals a close correlation, providing the authors with confidence that the simulation results accurately reflect the physical outcomes for each design of the fastener. The simulation results indicate that each method outperformed the original design, which had a thread depth and angle of 1.21 mm and 30°, respectively. The cladding fastener designed using the mathematical model-based method appears to have superior performance compared to the cladding fasteners designed by other methods, specifically the GA and parametric sweep methods. However, the manufacturing of this fastener incurs higher costs due to the increased material used in its structure. Figure 15 illustrates the deformed rectangular sample resulting from the maximum pull-out force observed in one of the experiments.

Figure 15. Deformed Sample Due to Maximum Pull-out Force



a)
b)



c) **d)**

Figure 16. Fasteners Resulted from Different Optimization Methods, a) Original Design, b) GA Base Method, c) Parametric Sweep Method, d) Mathematical Model Based Method

VI. Conclusions

This study details three geometry optimization methods applied to a specific roof fastener made of austenitic steel 316. Initially, a genetic algorithm (GA)-based model was used to optimize the fastener's geometry for maximum pull-out force capacity. This was followed by the parametric sweep method, where a neural network was designed to predict the optimal geometry parameters. The third method involved a newly proposed mathematical model that considered the two key parameters of the fastener: thread depth and angle. These parameters were also used in the GA-based and parametric sweep methods. To validate the results, an experimental setup was created to test the steel-fastener assembly with a specific sheet thickness. The tests showed that the mathematical model outperformed the other two methods, though it came with higher weight and cost.

Acknowledgements

This research has been funded by The Sustainable Advanced Manufacturing (SAM) Project.
The SAM Project is a £10.9m project to support the implementation of product and process development and the introduction of technology within the SME manufacturing base in the North East Local Enterprise Partnership (NE LEP) area. The programme is a collaboration between the European Regional Development Fund (ERDF) and the University of Sunderland.
Special thanks to all members of the SAM Project team, the University of Sunderland for providing the research expertise and support for this project.

References

[1]. D.Henderson, J.Ginger, C.Leitch, G.Boughton, D.Falck, Tropical Cyclone Larry Damage to Buildings in the Innisfail Area, Technical Report 51, Cyclone Testing Station, James Cook University, Townsville, Australia, (2006).

[2]. G.N.Boughton, D.J.Falck, Tropical Cyclone George Damage to Buildings in the Port Hedland Area, Technical Report 52, Cyclone Testing Station, James Cook University, Townsville, Australia (2007).

[3]. M. Sivapathasundaram, M. Mahendran, New Pull-Out Capacity Equations for the Design of Screw Fastener Connections in Steel Cladding Systems, Thin-Walled Structures, 122 (2018) 439-451.

[4]. M.Mahendran, Pull-Through Strength of High Tensile Steel Cladding Systems, Australian Structural Engineering Transactions, 2 (1999), 37-50.

[5]. G. De Matteis, R.Landolfo, Mechanical Fasteners for Cladding Sandwich Panels: Interpretative Models for Shear Behavior, 35(1999) 61-79.

[6]. N. Korcz-Konkol, E. Urbanska-Galewska, Influence of Sheet/Purlin Fasteners Spacing on Shear Flexibility of the Diaphragm, MATEC web of Conferences 219, 02007, BalCon, (2018) .

[7]. D. Mahaarachchi, M. Mahendran, Finite Element Analysis and Design of Crest-Fixed Trapezoidal Steel Claddings with Wide Pans subject to Pull-Through Failures, Engineering Structures, 26 (2004) 1547-1559.

[8]. X. Ji, G. Huang, X. Zhang, G.A. Kopp, Vulnerability Analysis of Steel Roofing Cladding: Influence of Wind Directionality, Engineering Structures, 156 (2018) 587-597.

[9]. Y. Tamura, H. Ueda, H.Kikuchi, K.Hibi, S.Suganuma, B.Bienkiewicz, Proper Orthogonal Decomposition Study of Approach Wind-Building Pressure Correlation, J Wind Eng Ind Aerodyn, 72 (1997) 421-431.

[10]. B.J.Vickery, C.Bloxham, Internal Pressure Dynamics with a Dominant opening, J Wind Eng Ind Aerodyn, 41(1-3)(1992) 193-204.

[11]. Y.L.Xu, Fatigue Performance of Screw-Fastened Light-Gauge-Steel Roofing Sheets, Engineering Structures, 121(3) (1995) 389-398.

[12]. Y.L.Xu, Fatigue Damage Estimation of Metal Roof Cladding subject to Wind Loading, J Wind Eng Ind Aerodyn, 72 (1) (1997) 379-388.

[13]. X.Zhang, X.Chen, Assessing Probabilistic Wind Load Effects via a Multivariate Extreme Wind Speed Model: A Unified Framework to Consider Directionality and Uncertainty, J Wind Eng Ind Aerodyn 147 (2015) 30-42.

[14]. M.Zhao,M. Gu, Database-Assisted Wind Vulnerability Assessment for Metal Buildings, Proceedings of 13th International Conference on Wind Engineering, Amsterdam, Netherlands, (2011).

[15]. K.S.Kumar, Prediction of Wind-Induced Fatigue on Claddings of Low Buildings, Computers and Structures, 75(1) (2000) 31-44.

[16]. K.S.Kumar, T. Stathopoulos, Fatigue Analysis of Roof Cladding Under Simulated Wind Loading, Wind Engineering and Industrial Aerodynamics, 77(8) (1998) 171-183.

[17]. E.D.Jancauskas, M.Mahendran,G.R.Walker, Computer Simulation of the Fatigue Behavior of Roof Cladding during the Passage of A Tropical Cyclone, Wind Engineering and Industrial Aerodynamics, 51 (1994) 215-227.

[18]. D.Mahaarachchi, M.Mahendran, Wind Uplift Strength of Trapezoidal Steel Cladding with Closely Spaced Ribs, Wind Engineering and Industrial Aerodynamics, 97 (2009) 140-150.

[19]. M.Mahendran, D.Mahaarachchi, Cyclic Pull-Out Strength of Screwed Connections in Steel Roof and Wall Cladding Systems using Thin Steel Battens, Americal Society of Civil Structures (ASCE), 128(6) (2002) 771-778.

[20]. X.Ji, G.Huang, H.Zheng, Fragility Analysis of Steel Roofing Cladding using Wind Tunnel Data, Advances in Civil, Environmental, and Materials Research (ACEM16), Jeju Island, Korea, (2016).

[21]. D.J.Henderson, J.D.Ginger, G.A.Kopp, Wind Induced Fatigue of Metal Roof Cladding during Severe Tropical Cyclones, Structures Congress (ASCE), (2010).

[22]. V. Hassani, Z. Khabazi, F. Raspall, C. Banon, D. W. Rosen, Form-Finding and Structural Shape Optimization of the Metal 3D-Printed Multi-Branch Node with Complex Geometry, Computer-Aided Design and Applications, 17 (1) (2019) 205-225.

[23]. V. Hassani, Z. Khabazi, Form-Finding of the Metal 3D-Printed Node with Complex Geometry, LAMBERT Academic Publishing, (2019).

[24]. V. Hassani, H. A. Mehrabi, Z. Ibrahim, I. F. Ituarte, A Comparison between Parametric Structural Optimization Methods and Software-Based Topology Optimization of A Rectangular Sample Under Tensile Load for Additive Manufacturing Processes, International Journal of Engineering Research and Applications, 11 (2) (2021) 37-58.

[25]. V. Hassani, Z. Khabazi, H. A. Mehrabi, C. Gregg, R. W. O'Brien, Rationalization Algorithm for A Topologically-Optimized Multi-Branch Node for Manufacturing by Metal Printing, Journal of Building Engineering, 29 (2019) 101146.

[26]. V. Hassani, H. A. Mehrabi, C. Gregg, R. W. O'Brien, I. F. Ituarte, T. Tjahjowidodo, Multi-Material Composition Optimization vs Software-Based Single-Material Topology Optimization of A Rectangular Sample under Flexural Load for Fused Deposition Modeling Process, Journal of Materials Science Forum, 1042 (2021) 23-44.

[27]. V. Hassani, A. Morris, Z. Ibrahim, I. Abubakar, H. Mehrabi, R. W. O'Brien, A Mathematical Model for A Cladding Fastener to Estimate the Maximum Pull-out Force Capacity, Journal of Physics: Conference Series, 1529 (052053) (2020).

[28]. Eurocode 3 – Design of Steel Structures – Part 1-3: General Rules – Supplementary Rules for Cold-Formed Members and Sheeting, (2006).