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Shear Stress Distribution in Double-lap Adhesive Joints Reinforced with Nylon Fabric: Numerical Investigation

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ABSTRACT

Nowadays there are an increasing number of industrial fields in which adhesive technology finds application. The main reason for their growing interest in both science and production is due to the high structural efficiency of this type of joining. Numerous studies have investigated the stress distribution in the adhesive layer under unreinforced conditions. The present work analyzes the elastic shear stress distribution in double-lap adhesive joints between timber and float glass adherends, both in the classical configuration and with an introduction of a nylon reinforcement in the two-component (2K) structural epoxy adhesives layers. In particular, three geometric configurations were investigated: nylon placed on the inner adherend, outer adherend and both. The result showed how the presence of the nylon inclusion changes the stress distribution in the joint. Numerical modelling of the joints was carried out using FE ANSYS©19 software. The greatest reduction in peak adhesive stresses is achieved by placing the reinforcement at both interfaces of the adherends with the adhesives. In general, it can be observed that the insertion of the reinforcement layer leads to a reduction in peak shear stresses, resulting in a potential increase in the ultimate strength of the joint.

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NOMENCLATURE

EPX1	First epoxy adhesive	ρ	Density (kg/m^3)
EPX2	Second epoxy adhesive	ν	Poisson ratio (-)
URM	Unreinforced model	E	Young Modulus (MPa)
RM-G	Reinforced model with nylon on glass surfaces	RM-GT	Reinforced model with nylon on glass and timber surfaces
RM-T	Reinforced model with nylon on timber surfaces		

1. INTRODUCTION

Adhesive joints allow dissimilar materials to be joined together, resulting in structures with high mechanical performance and characterised by lightweight properties [1-3].

In numerous industrial applications (e.g., automotive [4], naval [5] and aerospace [6]), these characteristics are fundamental and therefore adhesive technology takes a preferential role over traditional joining methods, such as bolted or riveted joints [7-9].

Some of the most studied adhesive joints are single-lap (SLJ) and double-lap (DLJ) types [10-12]; both types are used to study adhesive shear joint behaviour [13]. Single-lap joints can join two dissimilar adherends and are usually designed to tensile strength to failure [14]; however, misalignment of the adherends with respect to the line of application of the load leads to the occurrence of bending moments that may cause the joint failure, as demonstrated in literature [15-17].

In contrast, double-lap joints overcome the bending moment problem due to its symmetrical geometry, as noted by Marchione [18]. Therefore, this type of joint is more suitable for studying the distribution of shear stresses.

Gaudenzi et al. [19] conducted an experimental campaign to investigate the presence of delamination induced in plastic-reinforced carbon fibre plates by low-

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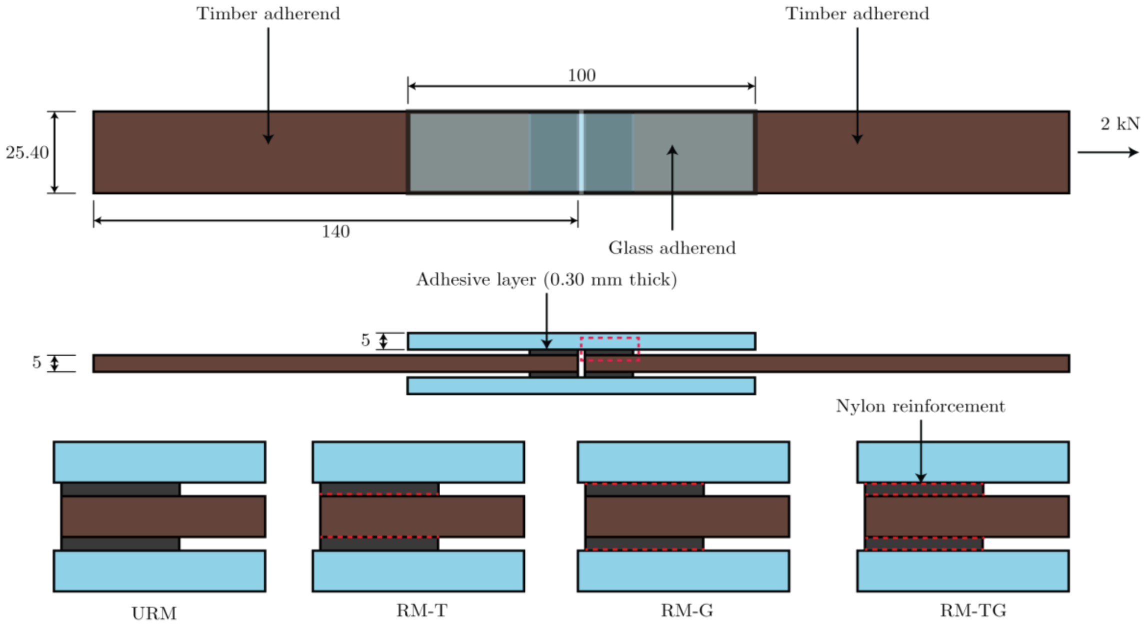

Figure 1. Double-lap adhesive joint, plan and section view (measures in mm)

velocity impacts. The results show the effectiveness of the SHM routine developed when a reduced number of sensors is desirable or mandatory.

Hu et al. [20] investigated the effect of non-woven carbon fabric (NWCT) composite adhesive layer on the bond strength and single-lap (SLJ) aluminium alloy joints. Wang et al. [21] investigated a simple method to apply and distribute multi-walled carbon nanotubes on sandblasted steel substrates. Kilik and Davies [22] studied the effect of introducing steel powder particles into the adhesive layer. The introduction of aluminium powder generally resulted in an increase in the static performance of the joints. The dynamic behaviour of the joints was experimentally analyzed and a better performance of copper powder than aluminium powder was observed.

The study of the vibrational behaviour of the double-lap adhesive joint was carried out by Marchione [23]. The influence of the elastic modulus and the density of adherends on the frequency for the various vibration modes was observed. In contrast, the presence of defects does not significantly influence the joint frequency. Further studies by the same author [24-26] have been investigated the potential of structural adhesives through analytical and numerical analyses.

As current research is oriented towards the study of new adhesive joint reinforcement techniques, and as stress measurement technologies often require the insertion of an outer layer into the adhesive joint, this paper analyzes the influence of the interposition of an intermediate adhesive layer. In particular, an FE study is conducted comparing the effect of the introduction of a P6 nylon layer in double-lap joints between mahogany adherends, further investigating experimental results obtained by the same author [27].

2. FINITE ELEMENT ANALYSIS

The present study investigates the stress state of a double-lap adhesive joint. The application of the present study is aimed at the industrial production of building components characterised by adhesive joints between timber and glass adherends. Since in their service life the stresses must remain in the elastic range in such elements, the plastic phase behaviour of the materials is not the subject of this study. The geometry of the joint considered is shown in Figure 1.

The inner clings are made of mahogany and have dimensions of 140 mm × 25.40 mm × 5 mm, representing its length, width and thickness, respectively. The outer adherends are made of transparent float glass and have the same geometric characteristics as the inner adherend. The bonding area has the dimensions of 12.70 mm × 25.40 mm, with a thickness of 0.30 mm.

3D modelling using the commercial software ANSYS©19 was used for the simulation. The model is meshed with PLANE 182, a 4-node structural solid and a base element size of 0.10 mm. The analyzed joints are made of Sapelly mahogany adherends and different adhesives (two epoxies). The same boundary conditions have been applied to all the configurations considered. The surfaces at the ends of fixed adherend are fixed with all DOF constrained (U1=U2=UR1 = UR2 = 0). The joints were loaded with a constant load of 2 kN on the inner timber adherend which is in the elastic range for the joints considered, as experimented and reported in literture [27].

The results are plotted on the midplane of the adhesive layer. The mechanical and physical characteristics of the adherends and adhesives are shown in Tables 1 and 2, respectively.

3. RESULTS AND DISCUSSION

This section reports the results obtained from the numerical analysis of double-lap adhesive joints reinforced with nylon fabric in different configurations. Figure 2 illustrates the stress distribution in unreinforced joints assembled with EPX1 epoxy adhesive. Figure 3 illustrates the stress distribution for unreinforced joints assembled with EPX2 adhesive.

The EPX1 adhesive shows a higher peak tension of 8.18 MPa, located at the end of the joint close to the load application. The higher stress intensity compared to EPX2 adhesive (+18%) is due to the higher stiffness of EPX1 adhesive (3000 MPa).

Figures 4-9 show the stress trends for the different reinforcement configurations, i.e. for the different positions of the nylon fabric in relation to the inner and outer adherends.

The placement of the nylon reinforcement near the interface between the adhesive and the timber adherends results in an intermediate reduction in peak stresses compared to other reinforced configurations.

TABLE 1. Adherends characteristics for the FE model

Mahogany timber		
E_t [MPa]	ρ [N/m^3]	$\boldsymbol{\nu}$ [-]
11000	7800	0.30
Float glass		
E_t [MPa]	ρ [N/m^3]	$\boldsymbol{\nu}$ [-]
75000	24000	0.30

TABLE 2. Adhesive's characteristics for the FE model

EPX 1	
E [MPa]	$\boldsymbol{\nu}$ [-]
3.00	0.35
EPX 2	
E [MPa]	$\boldsymbol{\nu}$ [-]
1.50	0.35

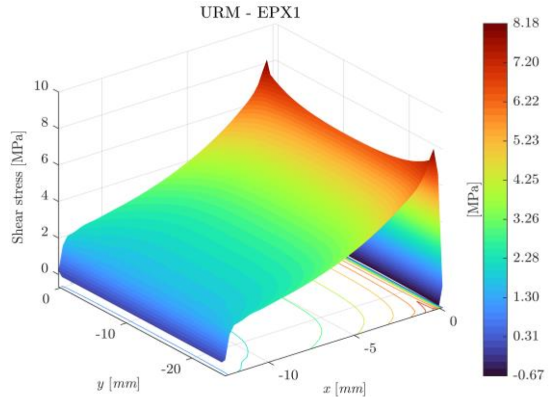

Figure 2. Shear stress distribution in the unreinforced joint, assembled with EPX1 adhesive

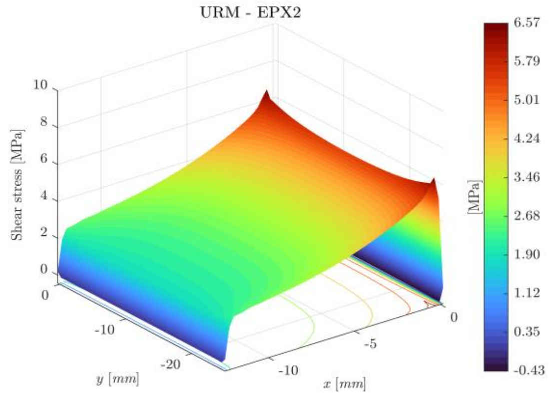

Figure 3. Shear stress distribution in the unreinforced joint, assembled with EPX2 adhesive

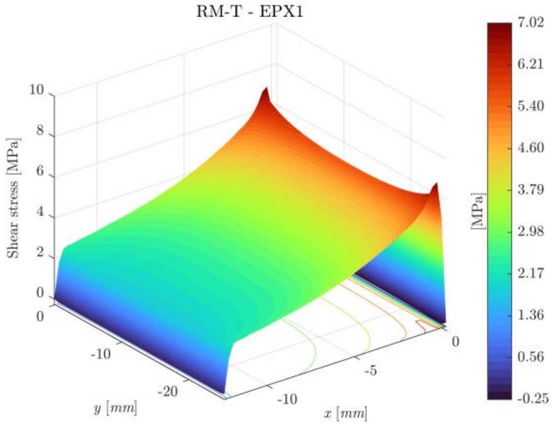

Figure 4. Shear stress distribution in the joint reinforced with nylon on timber surfaces, assembled with EPX1 adhesive

The introduction of the reinforcement on the glass surfaces results in a significant reduction in peak tensions, equalising the general trend.

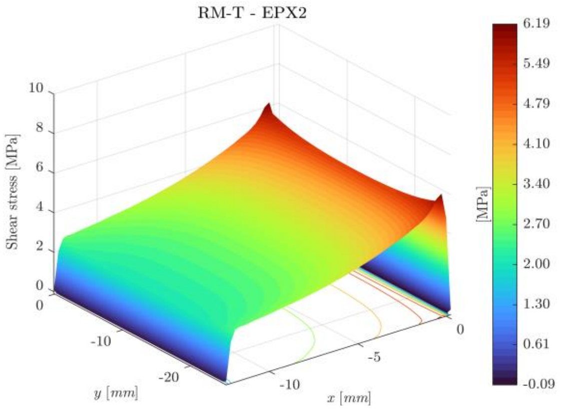

Figure 5. Shear stress distribution in the joint reinforced with nylon on timber surfaces, assembled with EPX2 adhesive

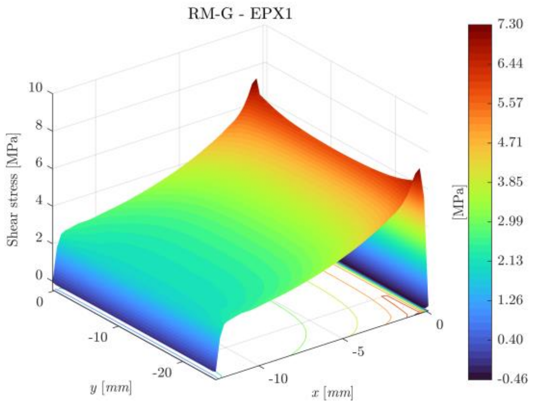

Figure 6. Shear stress distribution in the joint reinforced with nylon on glass surfaces, assembled with EPX1 adhesive

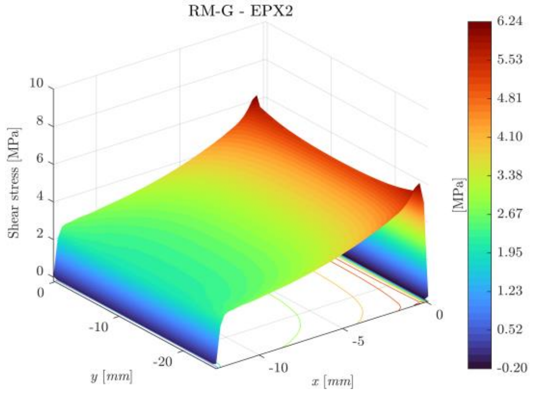

Figure 7. Shear stress distribution in the joint reinforced with nylon on glass surfaces, assembled with EPX2 adhesive

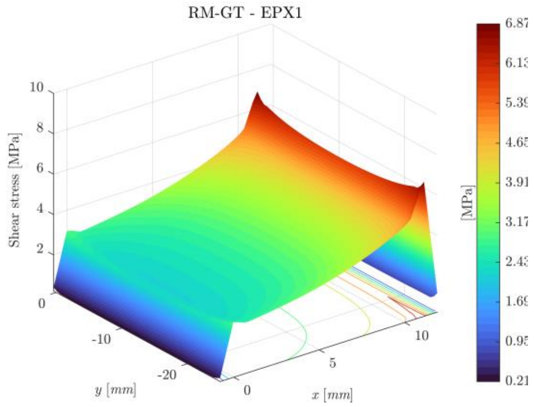

Figure 8. Shear stress distribution in the joint reinforced with nylon on both timber and glass surfaces, assembled with EPX1 adhesive

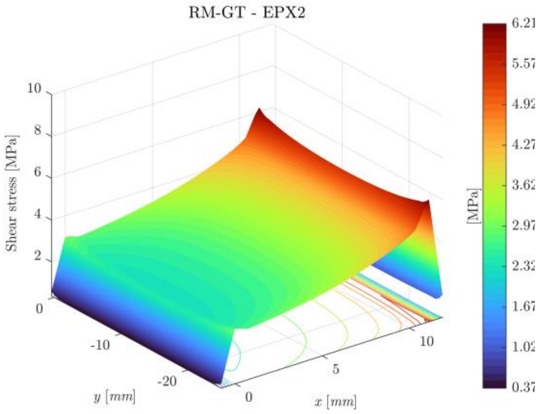

Figure 9. Shear stress distribution in the joint reinforced with nylon on both timber and glass surfaces, assembled with EPX2 adhesive

The greatest effect is obtained by placing the reinforcement in a double configuration, i.e., on both the glass and the mahogany adhesion. In this case, the tension peaks are significantly reduced (on average -2 MPa) compared to the unreinforced configuration.

This reinforcement method reduces the internal tension peaks under the same load, potentially increasing the ultimate strength of the adhesive layer. However, this change results in one or more potential new creep and crisis surfaces of the joint. Therefore, there is not always a beneficial effect on the overall behaviour of the joint.

Figure 10 illustrates the peak trends for the various configurations considered.

It is observed that the best effect is obtained by the double reinforcement, with the greatest reduction in stress peaks, due to an increase in deformability of the adhesive layer. Among the single reinforcements (i.e., applied either on the glass or on the mahogany adherends), the greatest reduction is determined by the positioning of the reinforcement on the timber adherend (i.e., the loaded adherend).

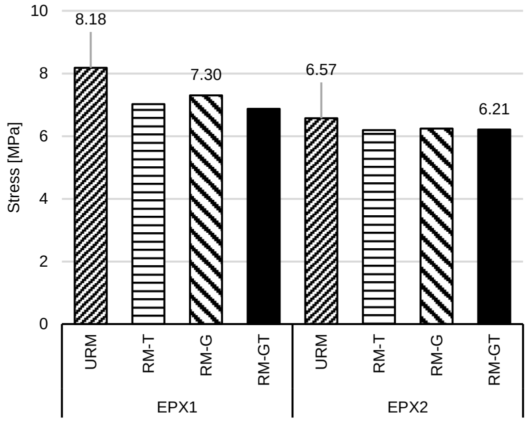

Figure 10. Shear stress peaks in the adhesive layer, for each configuration considered

4. CONCLUSIONS

Adhesive joints allow dissimilar materials to be joined together to create resulting lightweight structures characterized by a more uniform stress distribution than traditional joining technologies.

The present work numerically investigates the shear stress distribution within double-lap adhesive joints between wood and float glass adherends, assembled with two epoxy adhesives characterised by different elastic modulus.

The results showed that:

- The introduction of nylon reinforcement always results in a reduction of stress peaks at the end of the adhesive region, due to the increase in its deformability;
- The reduction in stress intensity potentially leads to an increase in the overall strength of the adhesive joint;
- Of the different reinforcement configurations investigated, the greatest reduction is that resulting from double reinforcement on both adherends;

  The introduction of the inclusive layer - or layers - into the adhesive may lead to the formation of additional failure interfaces and thus is prone to adhesive failure.

5. REFERENCES

1. Adams, R.D., Adams, R.D., Comyn, J., Wake, W.C. and Wake, W., "Structural adhesive joints in engineering, Springer Science & Business Media, (1997).
2. Da Silva, L.F., Adams, R. and Gibbs, M., "Manufacture of adhesive joints and bulk specimens with high-temperature adhesives", ***International Journal of Adhesion and Adhesives***, Vol. 24, No. 1, (2004), 69-83. https://doi.org/https://doi.org/10.1016/S0143-7496(03)00101-5.
3. Yousefsani, S.A., Tahani, M. and Selahi, E., "Analytical solution of stress field in adhesively bonded composite single-lap joints under mechanical loadings", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 27, No. 3, (2014), 475-486. https://doi.org/10.5829/idosi.ije.2014.27.03c.16
4. Quini, J.G. and Marinucci, G., "Polyurethane structural adhesives applied in automotive composite joints", ***Materials Research***, Vol. 15, (2012), 434-439. https://doi.org/10.1590/S1516-14392012005000042
5. Parate, B.A., "Propellant actuated device for parachute deployment during seat ejection for an aircraft application", ***HighTech and Innovation Journal***, Vol. 1, No. 3, (2020), 112-120. https://doi.org/10.28991/HIJ-2020-01-03-03
6. Hadjez, F. and Necib, B., "Experimental characterization and numerical modelling analyses of nano-adhesive-bonded joints", ***Frattura ed Integrità Strutturale***, Vol. 12, No. 44, (2018), 94-105. https://doi.org/10.3221/IGF-ESIS.44.08
7. da Silva, L.F.M., Öchsner, A. and Adams, R.D., "Handbook of adhesion technology, Springer, Vol. 1, (2011).
8. Mays, G.C. and Hutchinson, A.R., "Adhesives in civil engineering, Cambridge University Press Cambridge, UK:, Vol. 32, (1992).
9. Lees, W., "Adhesives in engineering design, Springer, (1984).
10. Ciupack, Y., Pasternak, H., Mette, C., Stammen, E. and Dilger, K., "Adhesive bonding in steel construction-challenge and innovation", ***Procedia Engineering***, Vol. 172, (2017), 186-193. https://doi.org/10.1016/j.proeng.2017.02.048
11. Stazi, F., Giampaoli, M., Rossi, M. and Munafò, P., "Environmental ageing on gfrp pultruded joints: Comparison between different adhesives", ***Composite Structures***, Vol. 133, (2015), 404-414. https://doi.org/10.1016/j.compstruct.2015.07.067
12. Tannert, T., Vallée, T. and Hehl, S., "Probabilistic strength prediction of adhesively bonded timber joints", ***Wood science and technology***, Vol. 46, No. 1, (2012), 503-513. https://doi.org/10.1007/s00226-011-0424-0
13. da Silva, L.F., das Neves, P.J., Adams, R. and Spelt, J., "Analytical models of adhesively bonded joints—part i: Literature survey", ***International Journal of Adhesion and Adhesives***, Vol. 29, No. 3, (2009), 319-330. https://doi.org/10.1016/j.ijadhadh.2008.06.005
14. Adams, R. and Peppiatt, N., "Stress analysis of adhesive-bonded lap joints", ***Journal of Strain Analysis***, Vol. 9, No. 3, (1974), 185-196. https://doi.org/10.1243/03093247V093185
15. Marchione, F., "Effect of hollow adherends on stress peak reduction in single-lap adhesive joints: Fe and analytical analysis", ***The Journal of Adhesion***, Vol. 98, No. 6, (2022), 656-676. https://doi.org/10.1080/00218464.2021.1995368
16. Owens, J.F. and Lee-Sullivan, P., "Stiffness behaviour due to fracture in adhesively bonded composite-to-aluminum joints i. Theoretical model", ***International Journal of Adhesion and Adhesives***, Vol. 20, No. 1, (2000), 39-45. https://doi.org/10.1016/S0143-7496(99)00013-5
17. Demir, K., Bayramoglu, S. and Akpinar, S., "The fracture load analysis of different support patches in adhesively bonded single-lap joints", ***Theoretical and Applied Fracture Mechanics***, Vol. 108, (2020), 102653. https://doi.org/10.1016/j.tafmec.2020.102653
18. Marchione, F., "Stress distribution in double-lap adhesive joints: Effect of adherend reinforcement layer", ***International Journal of Adhesion and Adhesives***, Vol. 105, (2021), 102780. https://doi.org/10.1016/j.ijadhadh.2020.102780
19. Gaudenzi, P., Nardi, D., Chiappetta, I., Atek, S., Lampani, L., Pasquali, M., Sarasini, F., Tirilló, J. and Valente, T., "Sparse sensing detection of impact-induced delaminations in composite

laminates", ***Composite Structures***, Vol. 133, (2015), 1209-1219. https://doi.org/10.1016/j.compstruct.2015.08.052

20. Hu, Z., Kong, H., Tao, L., Qiao, M., Yu, D., Lu, F., Dawelbeit, A. and Yu, M., "Effect of nonwoven carbon tissue-reinforced epoxy resin adhesive layer on the single lap bonding strength of aluminum alloy joints", ***ACS omega***, Vol. 6, No. 37, (2021), 23802-23813. https://doi.org/10.1021/acsomega.1c02635
21. Wang, B., Hu, X., Hui, J., Lu, P. and Jiang, B., "Cnt-reinforced adhesive joint between grit-blasted steel substrates fabricated by simple resin pre-coating method", ***The Journal of Adhesion***, Vol. 94, No. 7, (2018), 529-540. https://doi.org/10.1080/00218464.2017.1301255
22. Kilik, R. and Davies, R., "Mechanical properties of adhesive filled with metal powders", ***International Journal of Adhesion and Adhesives***, Vol. 9, No. 4, (1989), 224-228. https://doi.org/10.1016/0143-7496(89)90065-1
23. Marchione, F., "Investigation of vibration modes of double-lap adhesive joints: Effect of slot", ***International Journal of Engineering, Transactions A Basics***, Vol. 33, No. 10, (2020), 1917-1923. https://doi.org/10.5829/IJE.2020.33.10A.10
24. Marchione, F., "Analytical investigation on the stress distribution in structural elements reinforced with laminates subjected to axial loads", ***International Journal of Engineering, Transactions A: Basics***, Vol. 35, No. 4, (2022), 692-697. https://doi.org/10.5829/IJE.2022.35.04A.08
25. Marchione, F., "Analytical stress analysis in single-lap adhesive joints under buckling", ***International Journal of Engineering, Transactions B: Applications,***, Vol. 34, No. 2, (2021), 313-318. https://doi.org/10.5829/ije.2021.34.02b.02
26. Marchione, F., "Enhancement of stiffness in gfrp beams by glass reinforcement", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 34, No. 3, (2021), 615-620. https://doi.org/10.5829/ije.2021.34.03c.04
27. Marchione, F. and Munafò, P., "Experimental investigation on timber-glass double-lap adhesive joints reinforced with nylon fabric", ***Construction and Building Materials***, Vol. 275, (2021), 122152. https://doi.org/10.1016/j.conbuildmat.2020.122152

Persian Abstract

تا به امروز، بخش های صنعتی که فناوری چسب در آنها کاربرد پیدا می کند، همیشه در حال رشد هستند. دلیل اصلی علاقه روزافزون آنها به هر دو حوزه علمی و تولیدی به دلیل کارایی بالای ساختاری این نوع اتصالات است. مطالعات متعددی به بررسی توزیع تنش ها در لایه چسب در شرایط غیر مسلح پرداخته است. این کار روند تنش های برشی را در اتصالات چسب دولاپی بین چسب های چوب و شیشه فلوت، هم در پیکربندی کلاسیک و هم با معرفی یک تقویت کننده نایلونی در لایه چسب اپوکسی ساختاری دو جزیی (2K) تحلیل می کند. به طور خاص، سه پیکربندی هندسی مورد بررسی قرار گرفت: نایلون قرار گرفته بر روی چسبندگی داخلی، خارجی و روی هر دو. نتیجه نشان می دهد که چگونه حضور نایلون باعث تغییر توزیع تنش ها در اتصال می شود. مدل سازی عددی اتصالات با استفاده از نرم افزار FE ANSYS © 19 انجام شد. بیشترین کاهش در کشش پیک چسب با قرار دادن آرماتور در هر دو سطح مشترک چسب با چسب ها به دست می آید. به طور کلی می توان گفت که قرار دادن لایه تقویت کننده منجر به کاهش پیک های تنش برشی و در نتیجه افزایش بالقوه در استحکام نهایی اتصال می شود.