Statistical Assessment of the Strength of the Connection CM-Pasting

N Linkov

1Moscow State University of Civil Engineering National Research University, 26 Yaroslavskoye Shosse, Moscow, Russia

E-mail: n.v.linkov@yandex.ru

Abstract. The bearing capacity of the “CM-pasting” joint is determined by the strength of the adhesive bonds between the epoxy matrix and the contact surface of the wooden element, as well as the strength of the composite material (CM) in the joining joint. The article presents the results of testing samples of CM-joints in 1, 2 and 3 layers of fiberglass with a thickness of the composite material \( t_{km} = 0.45 \text{ mm}, 0.8 \text{ mm} \) and \( 1.2 \text{ mm} \), respectively, the results of a statistical evaluation of the strength of the CM-bonding joint different thickness of the composite material in the compound. 36 samples of the compound were tested, 12 samples of CM-compound for each thickness of the composite material. The calculated bearing capacity of the samples, the linear bearing capacity of the “CM-pasting” compound for shear, the resistance of the “CM-pasting” joint to shear were determined.

1. Introduction
The joining of wooden elements with composite materials using epoxy adhesives [1–7] is part of the practice of creating new and enhancing existing wooden structures. The connection "CM-pasting", developed in NRU MGSU and performed on the basis of epoxy matrix and fiberglass, is formed on the outer surfaces of wooden structures and is used to restore the service life, strengthen and increase the bearing capacity of wooden structures [8]. The bearing capacity of the “CM-pasting” joint is determined by the strength of the adhesive bonds between the epoxy matrix and the contact surface of the wooden element and the strength of the composite material (CM) in the joining joint [1, 9, 10]. Composite material in the compound " CM-pasting " includes a matrix of cold curing based on epoxy resin “ED-20” (100 weight parts) and hardener “PEPA” (15 weight parts) and the reinforcing component in the form of glass fabric T-13 plain weave 0.27 mm thick, thread from aluminosilicate glass.

2. Statement of the problem
For a statistical evaluation of the strength characteristics of the CM-pasting compound, we used data [1, 11, 12], obtained by us when testing samples of CM-joints in 1, 2 and 3 layers of fiberglass with a composite material thickness \( t = 0.45 \text{ mm} \), \( 0.8 \text{ mm} \) and \( 1.2 \text{ mm} \), respectively, where 6 samples were tested for each thickness of the CM. To ensure the reliability of the statistical analysis results, the required number of samples of the CM-pasting compounds for each thickness of the composite material in the CM connection was determined taking into account the actual average coefficient of
variation for the breaking load obtained from testing the samples, which amounted to \( \nu = 10.5\% \), required accuracy rating \( \rho = 5\% \) and confidence indicator \( \eta = 1.65 \) for confidence level \( 0.95 \) \( n=12 \).

3. Tests of the samples with different thickness

In addition, six samples were tested for each thickness of the composite material in the “CM-pasting” compounds \( t=0.45 \text{ mm}, 0.8 \text{ mm} \) and \( 1.2 \text{ mm} \). Symmetric double-cut samples (Figure 1) are made of boards with a section of \( 40 \times 90 \text{ mm} \) after gouging. The working area of the pasting area with composite material on one side of the sample was \( 120 \times 150 \text{ mm} \), the seam length was \( 150 \text{ mm} \). Composite material consists of a matrix in the form of hardened epoxy resin ED-20 and the accepted number of layers of glass fabric: with a thickness of \( t = 0.45 \text{ mm} \) - 1 layer, for \( t = 0.8 \text{ mm} \) two layers and for \( t = 1.2 \text{ mm} \) 3 layers fiberglass. The loading of the samples was carried out in steps at a constant speed without unloading until destruction. The destruction of the samples was brittle and was accompanied by a cut of the composite material along the joints, as well as the detachment of the CM-pasting due to the violation of the adhesive bonds between the composite material and the surface of the wooden element. Assessment and determination of the bearing capacity of the compounds "CM-pasting" conducted according to the method of CNIISK in accordance with "Wooden constructions.

![Figure 1](image-url)

**Figure 1.** Samples of compounds "CM-pasting": 1 - joined wooden elements; 2 - joint seam \( t = 1\text{ mm} \); 4 - joint, creating adhesive bonds at the border of the section "KM-wood".

4. Results

Table 1 presents the results of determining the calculated bearing capacity of compounds "CM-pasting" according to experimental data.

| №  | \( N_t \), kN | \( t' \), sec | \( t \), sec | \( K_{xp} \) | \( N_p \), kN | \( T_r \), kN/cm | \( R \), MPa |
|----|--------------|---------------|-------------|-------------|-------------|----------------|-----------|
| 1  | 27.00        | 300           | 7.85        | 3.01        | 8.97        | 0.149          | 33.21     |
| 2  | 25.00        | 190           | 4.97        | 3.05        | 8.20        | 0.137          | 30.37     |
|   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Middle |
|---|---|---|---|---|---|---|---|---|---|----|----|----|--------|
|   | 25.00 | 220 | 5.76 | 3.04 | 8.23 | 0.137 | 30.49 |
| 4  | 23.90 | 930 | 24.35 | 2.92 | 8.19 | 0.137 | 30.34 |
| 5  | 23.80 | 900 | 23.56 | 2.92 | 8.15 | 0.136 | 30.18 |
| 6  | 31.00 | 1860 | 48.69 | 2.86 | 10.84 | 0.181 | 40.14 |
| 7  | 24.20 | 240 | 6.28 | 3.03 | 7.99 | 0.133 | 29.58 |
| 8  | 27.30 | 270 | 7.08 | 3.02 | 9.04 | 0.151 | 33.48 |
| 9  | 27.80 | 280 | 7.33 | 3.02 | 9.21 | 0.154 | 34.13 |
| 10 | 24.60 | 230 | 6.01 | 3.03 | 8.11 | 0.156 | 30.40 |
| 11 | 30.20 | 310 | 8.11 | 3.01 | 10.04 | 0.167 | 37.18 |
| 12 | 21.60 | 200 | 5.24 | 3.04 | 7.09 | 0.118 | 26.27 |
| Middle | 25.95 | | 3.00 | 8.67 | 0.14 | 32.12 |

2. KM-pasting, t\(\text{km}=0.8\) mm

|   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Middle |
|---|---|---|---|---|---|---|---|---|---|----|----|----|--------|
| 1  | 33.50 | 320 | 8.38 | 3.01 | 11.14 | 0.186 | 23.22 |
| 2  | 37.00 | 255 | 6.68 | 3.02 | 12.23 | 0.204 | 25.48 |
| 3  | 27.60 | 158 | 4.14 | 3.06 | 9.01 | 0.150 | 18.76 |
| 4  | 31.00 | 1880 | 49.21 | 2.86 | 10.84 | 0.181 | 22.58 |
| 5  | 40.00 | 2020 | 52.88 | 2.85 | 14.02 | 0.234 | 29.20 |
| 6  | 32.00 | 2215 | 57.98 | 2.85 | 11.24 | 0.187 | 23.42 |
| 7  | 32.70 | 315 | 8.24 | 3.01 | 10.87 | 0.181 | 22.65 |
| 8  | 33.20 | 340 | 8.89 | 3.00 | 11.06 | 0.184 | 23.05 |
| 9  | 37.30 | 380 | 9.95 | 2.99 | 12.47 | 0.208 | 25.97 |
| 10 | 39.30 | 380 | 9.96 | 2.99 | 13.14 | 0.219 | 27.37 |
| 11 | 31.50 | 320 | 8.39 | 3.01 | 10.48 | 0.175 | 21.83 |
| 12 | 27.10 | 260 | 6.80 | 3.02 | 8.96 | 0.149 | 18.68 |
| Middle | 33.52 | | 2.97 | 11.29 | 0.19 | 23.52 |

3. CM-pasting, t\(\text{km}=1.2\) mm

|   | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Middle |
|---|---|---|---|---|---|---|---|---|---|----|----|----|--------|
| 1  | 41.20 | 260 | 6.81 | 3.02 | 13.63 | 0.227 | 18.93 |
| 2  | 40.50 | 245 | 6.41 | 3.03 | 13.37 | 0.223 | 18.58 |
| 3  | 37.10 | 180 | 4.71 | 3.05 | 12.15 | 0.202 | 16.87 |
| 4  | 46.00 | 2160 | 56.54 | 2.85 | 16.15 | 0.269 | 22.43 |
| 5  | 43.10 | 2170 | 56.81 | 2.85 | 15.13 | 0.252 | 21.02 |
| 6  | 48.50 | 2990 | 78.27 | 2.82 | 17.19 | 0.287 | 23.88 |
| 7  | 49.20 | 470 | 12.30 | 2.97 | 16.54 | 0.276 | 22.97 |
| 8  | 40.80 | 410 | 10.73 | 2.99 | 13.67 | 0.228 | 18.98 |
| 9  | 40.90 | 420 | 10.99 | 2.98 | 13.71 | 0.228 | 19.04 |
| 10 | 42.50 | 430 | 11.26 | 2.98 | 14.25 | 0.238 | 19.80 |
| 11 | 46.50 | 460 | 12.04 | 2.98 | 15.62 | 0.260 | 21.70 |
| 12 | 36.50 | 350 | 9.17 | 3.00 | 12.17 | 0.203 | 16.91 |
| Middle | 42.73 | | 2.96 | 14.47 | 0.24 | 20.09 |
From the consideration of table 1 we see that with an increase in the thickness of the composite material in the CM-pasting, the linear bearing capacity for shearing \( T \) increases: with an increase in the thickness of the pasting 2 times \( T \), it increases 1.3 times, with an increase in the thickness of the pasting 3 times \( T \) increases 1.67 times - an increase in the bearing capacity of the KM-bonding compound is not proportional to an increase in the thickness of the composite material. Consider the connection resistance to the shear \( R \), where with increasing the thickness of the CM-pasting by 2 and 3 times the shear resistance \( R \) decreases by 1.34 and 1.59 times respectively. This confirms on a statistically substantiated number of tests the conclusion [1, 10] that an increase in the thickness of the composite material causes a complication of the nature of the work and the destruction of the CM compound, when the carrying capacity of the CM-pasting “on the cut” increases and the decay of the adhesive bonds between material and the surface of the wooden elements of the CM-connection. Table 2 presents the results of statistical processing of the strength characteristics of the compound "CM-pasting". From table 2 it follows that for all the considered parameters of the stress state of the “CM-pasting” compound, the reliability of the results obtained is confirmed by the results of statistical processing. The variation coefficients for the force factors - the calculated bearing capacity \( N \), linear load bearing capacity for shearing \( T \) and resistance to shear \( R \) were 11.4% -13.3%, which does not exceed the maximum values of 15-20% for wood, the accuracy rate \( \rho \) was 3.3-3.9%, which does not exceed the maximum value of \( \rho = 5\% \) established in the field of the timber industry and wooden structures.

**Table 2.** Strength characteristics of the compound "CM-pasting". Statistical processing of \( n = 12 \) pieces of samples.

| \( \# \) | Statistical processing indicators | Notation | Properties under study |
|---|---|---|---|
|   |   | \( K_{xp} \) | \( N_p \) | \( T \) | \( R \) |
| 1 | CM-pasting, \( t=0,45 \) mm, \( n=12 \) |   |   |   |   |
| 1 | Average | M | 3.00 | 8,67 | 0,14 | 32,12 |
| 2 | Average deviation | S | 0.06 | 1,01 | 0,02 | 3,75 |
| 3 | Variation coefficient | \( v, \% \) | 0,020 | 0,117 | 0,117 | 0,117 |
| 4 | Variation mistake | m | 0,018 | 0,292 | 0,005 | 1,082 |
| 5 | Accuracy rate | \( \rho, \% \) | 0,59 | 3,37 | 3,37 | 3,37 |
| 2 | CM-pasting, \( t=0,8 \) mm, \( n=12 \) |   |   |   |   |
| 6 | Average | M | 2,97 | 11,29 | 0,19 | 23,52 |
| 7 | Average deviation | S | 0,07 | 1,50 | 0,03 | 3,13 |
| 8 | Variation coefficient | \( v, \% \) | 0,025 | 0,133 | 0,133 | 0,133 |
| 9 | Variation mistake | m | 0,022 | 0,434 | 0,007 | 0,904 |
| 10 | Accuracy rate | \( \rho, \% \) | 0,73 | 3,84 | 3,84 | 3,84 |
| 3 | CM-pasting, \( t=1,2 \) mm, \( n=12 \) |   |   |   |   |
| 1 | Average | M | 2,96 | 14,47 | 0,24 | 20,09 |
| 2 | Average deviation | S | 0,08 | 1,66 | 0,03 | 2,30 |
| 3 | Variation coefficient | \( v, \% \) | 0,026 | 0,114 | 0,114 | 0,114 |
| 4 | Variation mistake | m | 0,022 | 0,478 | 0,008 | 0,664 |
| 5 | Accuracy rate | \( \rho, \% \) | 0,75 | 3,30 | 3,30 | 3,30 |

Let us estimate the reliability of the difference between the average values of the calculated shear resistance of the “CM-pasting” joint for different thickness of the composite material: \( t=0,45 \) mm and \( 0,8 \) mm: \( 6,1>3,75 \); the significance of the difference is confirmed; \( t=0,8 \) mm and \( 1,2 \) mm: \( 3,06<3,75 \); significance of the difference is not confirmed.

5. Summary

Based on the tests and calculations performed, the following conclusions are made:
5.1. The obtained results show that an increase in the thickness of the composite material over $t > 1.2$ mm will not lead to a decrease in the calculated shear resistance $R$ of the “CM-pasting” compound.

On the basis of the tests performed and the calculations made, the following conclusions were made:

The calculated bearing capacity $N_p$ of the CM-pasting compound based on an epoxy matrix and glass fabric with a thickness of composite material from $t=0.45$ mm to $t=1.2$ mm ranged from 8.67 kN to 14.47 kN, which shows the suitability of CM-compounds for use in supporting and enclosing building structures of solid and laminated wood.

5.2. The obtained results show that an increase in the thickness of the composite material over $t > 1.2$ mm will not lead to a decrease in the calculated shear resistance $R$ of the “CM-pasting” compound.

On the basis of the tests performed and the calculations made, the following conclusions were made:

The calculated bearing capacity $N_p$ of the CM-pasting compound based on an epoxy matrix and glass fabric with a thickness of composite material from $t=0.45$ mm to $t=1.2$ mm ranged from 8.67 kN to 14.47 kN, which shows the suitability of CM-compounds for use in supporting and enclosing building structures of solid and laminated wood.

5.3. Corresponding to the calculated bearing capacity, the resistance of the “CM-pasting” joint to the shift $R$, calculated according to the CNIISK method taking into account the duration of the load, was $R = 20.09$ MPa, 23.52 MPa, 32.12 MPa with a composite material with a thickness of $t=1.2$ mm, 0.8 mm and 0.45 mm, respectively. Corresponding to the calculated bearing capacity, the long-term resistance of the “KM-pasting” joint to the cut-off $T_{km}$ calculated using the CNIISK method, taking into account the duration of the load, was $T_{km} = 0.24$ kN / cm, 0.19 kN / cm, 0.14 kN / cm with composite material with a thickness of $t_{km} = 1.2$ mm, 0.8 mm and 0.45 mm, respectively.

5.4. Estimation of the reliability of the difference between the average values of the calculated shear resistance of the CM-pasting compound for different thickness of the composite material showed that an increase in the thickness of the composite material more than $t > 1.2$ mm will not lead to a decrease in the calculated shear resistance $R$ of the connection.

References

[1] Davidyuk A 2016 Concrete and reinforced concrete vol 2 pp.13-16
[2] Tusnin A 2017 Industrial and civil engineering vol 9 pp 25-29
[3] Linkov V, Linkov N 2006 Construction Engineering vol 10 pp 66 – 70
[4] Roshchina 2014 Scientific and Technical Bulletin of the Volga region vol 5 pp 293-296
[5] Linkov N 2013 Vestnik MGSU vol 4 pp 20-22
[6] Linkov N 2016 Scientific Review vol 17 pp.10-15
[7] Linkov N 2017 Technology textile industry vol 3 pp 103-108
[8] Linkov N 2018 Technology textile industry vol 3 pp 75-80
[9] Ponomarev A 2016 Engineering and Construction Journal vol 8 pp 45-57
[10] Patnaik A, Bauer C 2004 Advanced Composites for Bridges and structures conference
[11] Colombi P 2003 Experimental studies and calculation of building structures pp 117-124
[12] Pyatikrestovsky K 2017 Materials Physics and Mechanics vol 1-2 pp 56-58
[13] Rzhansitsyn A 1948 Theory of composite rods for structures Stroyizdat 192 p
[14] Rzhansitsyn A 1986 Composite rods and plates Stroyizdat 316 p