**Prediction and reliability analysis of ultimate axial strength for outer circular CFRP-strengthened CFST columns using TGAN and novel hybrid ML model**

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**1. TGAN results**

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**Fig. S-1.** Distribution comparison of the real and 500 TGAN data samples.

**Table S-1** Results of500 TGAN data samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |
| Unit | (mm) | (mm) | (mm) | (MPa) | (mm) | (MPa) | (GPa) | (MPa) | (kN) |
| Min | 200.743 | 100.006 | 1.516 | 224.379 | 0.112 | 3400.007 | 224.851 | 15.909 | 541.634 |
| Mean | 504.758 | 177.065 | 3.138 | 291.570 | 0.332 | 3747.318 | 241.378 | 49.673 | 2909.418 |
| Max | 779.990 | 260.000 | 9.982 | 385.743 | 0.815 | 4810.548 | 257.000 | 112.642 | 7779.661 |
| SD | 148.371 | 60.747 | 1.588 | 40.359 | 0.172 | 392.381 | 9.285 | 22.938 | 1743.211 |
| CoV | 0.294 | 0.343 | 0.506 | 0.138 | 0.517 | 0.105 | 0.038 | 0.462 | 0.599 |

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**Fig. S-2.** Distribution comparison of the real and 1,000 TGAN data samples.

**Table S-2** Results of1,000 TGAN data samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |
| Unit | (mm) | (mm) | (mm) | (MPa) | (mm) | (MPa) | (GPa) | (MPa) | (kN) |
| Min | 201.037 | 100.003 | 1.473 | 226.334 | 0.114 | 3400.004 | 225.170 | 14.699 | 482.744 |
| Mean | 513.112 | 179.286 | 3.003 | 292.992 | 0.346 | 3735.810 | 241.618 | 51.688 | 2974.383 |
| Max | 779.984 | 260.000 | 9.874 | 385.781 | 0.830 | 4867.780 | 257.000 | 112.691 | 7773.174 |
| SD | 152.540 | 61.072 | 1.410 | 40.451 | 0.176 | 385.768 | 8.722 | 23.343 | 1781.340 |
| CoV | 0.297 | 0.341 | 0.470 | 0.138 | 0.508 | 0.103 | 0.036 | 0.452 | 0.599 |

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**Fig. S-3.** Distribution comparison of the real and 1,500 TGAN data samples.

**Table S-3** Results of1,500 TGAN data samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |
| Unit | (mm) | (mm) | (mm) | (MPa) | (mm) | (MPa) | (GPa) | (MPa) | (kN) |
| Min | 200.148 | 100.000 | 1.467 | 224.017 | 0.112 | 3400.001 | 224.546 | 14.802 | 445.819 |
| Mean | 512.685 | 178.137 | 3.008 | 292.235 | 0.345 | 3719.069 | 240.919 | 50.928 | 2914.504 |
| Max | 779.997 | 260.000 | 9.993 | 385.960 | 0.833 | 4878.547 | 257.000 | 112.691 | 7781.239 |
| SD | 149.478 | 59.962 | 1.469 | 39.645 | 0.179 | 380.733 | 8.610 | 24.074 | 1745.113 |
| CoV | 0.292 | 0.337 | 0.488 | 0.136 | 0.518 | 0.102 | 0.036 | 0.473 | 0.599 |

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**Fig. S-4.** Distribution comparison of the real and 2,000 TGAN data samples.

**Table S-4** Results of2,000 TGAN data samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |  |  |
| Unit | (mm) | (mm) | (mm) | (MPa) | (mm) | (MPa) | (GPa) | (MPa) | (kN) |
| Min | 200.548 | 100.000 | 1.470 | 224.861 | 0.112 | 3400.000 | 224.881 | 15.174 | 457.832 |
| Mean | 505.624 | 174.665 | 3.136 | 293.582 | 0.341 | 3713.134 | 241.376 | 50.816 | 2877.998 |
| Max | 779.999 | 260.000 | 9.995 | 385.795 | 0.829 | 4878.215 | 257.000 | 112.692 | 7781.186 |
| SD | 153.258 | 61.100 | 1.558 | 41.704 | 0.175 | 371.936 | 8.565 | 24.098 | 1805.336 |
| CoV | 0.303 | 0.350 | 0.497 | 0.142 | 0.514 | 0.100 | 0.035 | 0.474 | 0.627 |

**2. The preliminary analysis's results**

**Table S-5** Results of 500 TGAN data samples combined with 213 experimental samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Model** | **Training-test ratio** | | | | | | | |
| **0.55-0.45** | **0.60-0.40** | **0.65-0.35** | **0.70-0.30** | **0.75-0.25** | **0.80-0.20** | **0.85-0.15** | **0.90-0.10** |
| 1 | **DT** | 0.745 | 0.776 | 0.759 | 0.819 | 0.768 | 0.796 | 0.799 | 0.852 |
| 2 | **RF** | 0.860 | 0.864 | 0.859 | 0.885 | 0.882 | 0.892 | 0.861 | 0.909 |
| 3 | **AB** | 0.814 | 0.814 | 0.829 | 0.831 | 0.832 | 0.826 | 0.833 | 0.841 |
| 4 | **GB** | 0.861 | 0.866 | 0.851 | 0.869 | 0.880 | 0.893 | 0.878 | 0.898 |
| 5 | **XGB** | 0.877 | 0.885 | 0.899 | 0.877 | 0.887 | 0.910 | 0.922 | 0.903 |
| **6** | **ET** | **0.924** | **0.938** | **0.928** | **0.939** | **0.942** | **0.947** | **0.937** | **0.951** |
| 7 | **HGB** | 0.874 | 0.869 | 0.882 | 0.892 | 0.903 | 0.905 | 0.916 | 0.918 |
| 8 | **LGBM** | 0.871 | 0.877 | 0.881 | 0.892 | 0.903 | 0.907 | 0.920 | 0.922 |
| 9 | **BAG** | 0.850 | 0.857 | 0.837 | 0.867 | 0.870 | 0.877 | 0.837 | 0.899 |
| Note: the results are based on the mean R2 of the 5 testing folds. | | | | | | | | | |

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**Fig. S-5.** Training-test ratio of 0.55-0.45.

**A diagram of training results

Description automatically generated with medium confidence**

**Fig. S-6.** Training-test ratio of 0.60-0.40.

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Description automatically generated with medium confidence

**Fig. S-7.** Training-test ratio of 0.65-0.35.

A diagram of training test

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**Fig. S-8.** Training-test ratio of 0.70-0.30.

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**Fig. S-9.** Training-test ratio of 0.75-0.25.

A diagram of training test

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**Fig. S-10.** Training-test ratio of 0.80-0.20.

A diagram of training test

Description automatically generated with medium confidence

**Fig. S-11.** Training-test ratio of 0.85-0.15.

A diagram of training test

Description automatically generated

**Fig. S-12.** Training-test ratio of 0.90-0.10.

**Table S-6** Results of 1,000 TGAN data samples combined with 213 experimental samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Model** | **Training-test ratio** | | | | | | | |
| **0.55-0.45** | **0.60-0.40** | **0.65-0.35** | **0.70-0.30** | **0.75-0.25** | **0.80-0.20** | **0.85-0.15** | **0.90-0.10** |
| 1 | **DT** | 0.869 | 0.869 | 0.861 | 0.875 | 0.843 | 0.852 | 0.874 | 0.873 |
| 2 | **RF** | 0.901 | 0.894 | 0.897 | 0.916 | 0.922 | 0.920 | 0.918 | 0.921 |
| 3 | **AB** | 0.848 | 0.818 | 0.824 | 0.832 | 0.849 | 0.839 | 0.828 | 0.833 |
| 4 | **GB** | 0.896 | 0.887 | 0.901 | 0.911 | 0.919 | 0.923 | 0.910 | 0.919 |
| 5 | **XGB** | 0.876 | 0.899 | 0.922 | 0.927 | 0.930 | 0.926 | 0.932 | 0.921 |
| **6** | **ET** | **0.933** | **0.933** | **0.937** | **0.946** | **0.947** | **0.943** | **0.946** | **0.945** |
| 7 | **HGB** | 0.898 | 0.904 | 0.917 | 0.915 | 0.924 | 0.925 | 0.932 | 0.930 |
| 8 | **LGBM** | 0.902 | 0.906 | 0.911 | 0.919 | 0.921 | 0.923 | 0.934 | 0.930 |
| 9 | **BAG** | 0.888 | 0.896 | 0.895 | 0.899 | 0.901 | 0.913 | 0.912 | 0.910 |
| Note: the results are based on the mean R2 of the 5 testing folds. | | | | | | | | | |

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**Fig. S-13.** Training-test ratio of 0.55-0.45.

**A diagram of training and training

Description automatically generated with medium confidence**

**Fig. S-14.** Training-test ratio of 0.60-0.40.

A graph showing different types of objects

Description automatically generated with medium confidence

**Fig. S-15.** Training-test ratio of 0.65-0.35.

A diagram of training test

Description automatically generated

**Fig. S-16.** Training-test ratio of 0.70-0.30.

A diagram of a graph

Description automatically generated

**Fig. S-17.** Training-test ratio of 0.75-0.25.

A diagram of training test

Description automatically generated

**Fig. S-18.** Training-test ratio of 0.80-0.20.

A diagram of training test

Description automatically generated

**Fig. S-19.** Training-test ratio of 0.85-0.15.

A diagram of training test

Description automatically generated

**Fig. S-20.** Training-test ratio of 0.90-0.10.

**Table S-7** Results of 1,500 TGAN data samples combined with 213 experimental samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Model** | **Training-test ratio** | | | | | | | |
| **0.55-0.45** | **0.60-0.40** | **0.65-0.35** | **0.70-0.30** | **0.75-0.25** | **0.80-0.20** | **0.85-0.15** | **0.90-0.10** |
| 1 | **DT** | 0.859 | 0.834 | 0.866 | 0.863 | 0.869 | 0.868 | 0.900 | 0.891 |
| 2 | **RF** | 0.905 | 0.905 | 0.917 | 0.923 | 0.927 | 0.933 | 0.935 | 0.935 |
| 3 | **AB** | 0.846 | 0.851 | 0.845 | 0.849 | 0.842 | 0.845 | 0.855 | 0.839 |
| 4 | **GB** | 0.913 | 0.907 | 0.921 | 0.921 | 0.926 | 0.926 | 0.929 | 0.928 |
| 5 | **XGB** | 0.919 | 0.932 | 0.927 | 0.934 | 0.944 | 0.947 | 0.942 | 0.951 |
| **6** | **ET** | **0.944** | **0.949** | **0.951** | **0.953** | **0.956** | **0.959** | **0.962** | **0.963** |
| 7 | **HGB** | 0.919 | 0.928 | 0.935 | 0.932 | 0.945 | 0.949 | 0.948 | 0.949 |
| 8 | **LGBM** | 0.921 | 0.929 | 0.937 | 0.930 | 0.940 | 0.947 | 0.949 | 0.949 |
| 9 | **BAG** | 0.900 | 0.899 | 0.903 | 0.907 | 0.917 | 0.929 | 0.926 | 0.926 |
| Note: the results are based on the mean R2 of the 5 testing folds. | | | | | | | | | |

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**Fig. S-21.** Training-test ratio of 0.55-0.45.

**A diagram of training results

Description automatically generated with medium confidence**

**Fig. S-22.** Training-test ratio of 0.60-0.40.

A diagram of a graph

Description automatically generated

**Fig. S-23.** Training-test ratio of 0.65-0.35.

A diagram of training test

Description automatically generated

**Fig. S-24.** Training-test ratio of 0.70-0.30.

A graph showing different colored lines

Description automatically generated with medium confidence

**Fig. S-25.** Training-test ratio of 0.75-0.25.

A diagram of training test

Description automatically generated

**Fig. S-26.** Training-test ratio of 0.80-0.20.

A diagram of training test

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**Fig. S-27.** Training-test ratio of 0.85-0.15.

A graph showing different types of training

Description automatically generated with medium confidence

**Fig. S-28.** Training-test ratio of 0.90-0.10.

**Table S-8** Results of 2,000 TGAN data samples combined with 213 experimental samples

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Model** | **Training-test ratio** | | | | | | | |
| **0.55-0.45** | **0.60-0.40** | **0.65-0.35** | **0.70-0.30** | **0.75-0.25** | **0.80-0.20** | **0.85-0.15** | **0.90-0.10** |
| 1 | **DT** | 0.870 | 0.866 | 0.890 | 0.884 | 0.890 | 0.877 | 0.881 | 0.926 |
| 2 | **RF** | 0.926 | 0.925 | 0.933 | 0.933 | 0.942 | 0.946 | 0.947 | 0.952 |
| 3 | **AB** | 0.871 | 0.865 | 0.861 | 0.866 | 0.866 | 0.870 | 0.871 | 0.869 |
| 4 | **GB** | 0.919 | 0.923 | 0.921 | 0.925 | 0.933 | 0.933 | 0.934 | 0.936 |
| 5 | **XGB** | 0.937 | 0.929 | 0.951 | 0.942 | 0.954 | 0.958 | 0.952 | 0.954 |
| **6** | **ET** | **0.962** | **0.963** | **0.962** | **0.963** | **0.969** | **0.969** | **0.969** | **0.972** |
| 7 | **HGB** | 0.946 | 0.945 | 0.941 | 0.948 | 0.952 | 0.952 | 0.956 | 0.960 |
| 8 | **LGBM** | 0.947 | 0.945 | 0.954 | 0.942 | 0.958 | 0.955 | 0.959 | 0.959 |
| 9 | **BAG** | 0.918 | 0.925 | 0.926 | 0.931 | 0.930 | 0.938 | 0.941 | 0.941 |
| Note: the results are based on the mean R2 of the 5 testing folds. | | | | | | | | | |

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**Fig. S-28.** Training-test ratio of 0.55-0.45.

**A graph showing a number of training tests

Description automatically generated with medium confidence**

**Fig. S-30.** Training-test ratio of 0.60-0.40.

A diagram of a graph

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**Fig. S-31.** Training-test ratio of 0.65-0.35.

A graph showing a training test

Description automatically generated with medium confidence

**Fig. S-32.** Training-test ratio of 0.70-0.30.

A graph of a graph showing the results of a test

Description automatically generated with medium confidence

**Fig. S-33.** Training-test ratio of 0.75-0.25.

A diagram of training test

Description automatically generated

**Fig. S-34.** Training-test ratio of 0.80-0.20.

A graph showing a training test

Description automatically generated with medium confidence

**Fig. S-35.** Training-test ratio of 0.85-0.15.

A graph of training test

Description automatically generated with medium confidence

**Fig. S-36.** Training-test ratio of 0.90-0.10.