e-Journal of Nondestructive Testing - ISSN 1435-4934 - www.ndt.net
14th European Conference on Non-Destructive Testing, Verona, Italy (ECNDT 2026)

AI-driven Prediction of Structural Steel Mechanical Properties Using Ultrasound and Eddy Current Testing

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1 Abstract

Reuse of structural steel can reduce embodied carbon but depends on reliable knowledge of the mechanical properties of reclaimed members. Conventional assessment relies on destructive tensile tests, which are costly, time-consuming, and difficult to scale. This study evaluates the use of ultrasound testing (UT), eddy current testing (ECT), and data-driven models to predict mechanical properties and classify the strength grade of salvaged structural steels. Specimens from reclaimed beam flanges and webs were tested in tension and measured using UT and ECT. Random forest (RF) model was used for strength-grade classification and property prediction. The ECT-based classifier achieved an accuracy of 0.92, while the UT-based classifier reached about 0.82. The UT-based yield strength model achieved a mean absolute percentage error of 5.86%, demonstrating that yield strength can be estimated with reasonable accuracy without prior knowledge of steel grade.

Keywords: Structural steel reuse, ultrasound testing, Eddy current testing, Machine learning, Yield strength prediction.

2 Introduction

Structural steel production is a major source of industrial CO_2 emissions, while steel reuse can reduce embodied carbon if the mechanical properties of reclaimed members are reliably known [1,2]. These properties are typically obtained from destructive tensile tests, which are costly and difficult to apply at scale [1,2]. Nondestructive testing (NDT) methods, such as ultrasound testing (UT) and eddy current testing (ECT), provide rapid measurements that correlate with tensile properties but do not directly give strength values [3–4]. This study investigates an NDT-based machine learning framework using UT and ECT features to classify steel grade and predict yield strength of salvaged structural steel from reclaimed I-sections.

3 Methodology

3.1 Data Collection Phase

UT and ECT were carried out on various steel sections of grades S275, S355, and S460. Tensile coupons were extracted from both flanges and webs (thickness ≈ 6–50 mm) and tested to determine the yield strength (R_e). Prior to measurements, a small area on each specimen was locally ground to remove rust, paint, and surface irregularities, ensuring proper probe contact and measurement reliability. From UT, the specimen thickness as well as the longitudinal wave velocity (V_l) and shear wave velocity (V_s) were measured at several locations and then averaged. ECT was subsequently performed at a frequency of 500 kHz using fixed probe settings to obtain the maximum voltage (V_{max}), maximum magnetic field intensity (H_{max}), peak-to-peak signal amplitude (A_{pp}), and phase angle (θ_{pp}).

3.2 Data Processing and Model Establishment

Three datasets were formed as of now: an ECT dataset for grade classification, a UT dataset for grade classification and a UT-tensile dataset for yield regression. ECT models use thickness, V_{max}, H_{max}, A_{pp}, and θ_{pp} as inputs; UT models use thickness, V_l, and V_s for regression, these UT features are combined with flange/web indicators together with the measured R_e. Random forest (RF) classifiers and regressor are trained and evaluated using an 80/20 train-test split with stratification by grade. Performance is summarized by accuracy and weighted F1 score for classification and by R^2, MAE and MAPE for regression.

4 Results and Discussion

Fig.1 presents, from left to right, the confusion matrix of the ECT-based grade classifier, the confusion matrix of the UT-based grade classifier, and the predicted versus measured yield strength obtained using the UT-based RF regressor. For the ECT classifier, most specimens are correctly identified, resulting in a test accuracy of 0.92 and a weighted F1-score of 0.87, with only a small number of S275 and S460 samples misclassified. The UT classifier attains an average accuracy of 0.821 and a weighted F1-score of 0.806 over 200 repeated 80/20 splits; in the representative split shown, most S355 specimens are correctly classified, while some S275 specimens are predicted as S355. In the yield strength regression plot, the predictions generally follow the 1:1 reference line, whereas the test set shows a more moderate performance with R^2 = 0.76, MAE = 20.16 N/mm², and MAPE = 5.86 %, indicating that yield strength can still be predicted within approximately five percent on average even without explicit grade information.

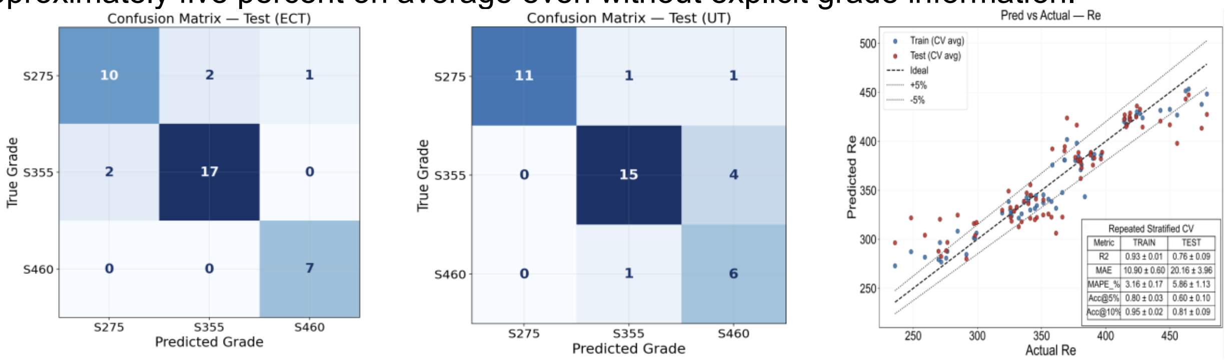

Fig. 1. From left to right: confusion matrix of the ECT based grade classifier, confusion matrix of the UT-based grade classifier, and UT-based RF prediction model (predicted versus true yield strength).

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