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Prediction of Compressive Strength and Elastic Modulus for Recycled Aggregate Concrete Based on AutoGluon

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Abstract: While the civil construction industry brings great convenience to life, the large amount of waste concrete also poses a significant problem of construction waste disposal. As one of the effective ways to utilize waste concrete, recycled aggregate concrete (RAC) can improve the environment while reducing the consumption of construction materials. This study aims to use AutoGluon (AG), an automated machine learning platform, to predict both the compressive strength and elastic modulus of RAC. Then the performance of AG is compared with traditional empirical formulas and multiple linear regression models. The determination coefficient (R^2) is chosen as one of the evaluation standards for predicting values. The results demonstrate that the WeightedEnsemble model of AG performed best in predicting both the compressive strength and elastic modulus, which provides a new method for the rapid and accurate prediction of the properties of RAC in engineering construction.

Keywords: AutoGluon; recycled aggregate concrete; machine learning; compressive strength; elastic modulus

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1. Introduction

With the continuous progress of urbanization, civil construction-related industries continue to develop. Numerous construction projects have produced much construction waste while improving people's lives. The statistical results illustrate that the average annual production of construction waste in China has reached 90 million tons, and there is a trend of year-on-year growth [1]. It is worth noting that concrete waste is the most significant component of construction waste, accounting for about 35% [1]. Currently, construction waste materials are mainly dealt with by landfill and accumulation, which not only causes a large amount of resource waste but also results in severe environmental pollution [2,3]. The current disposal method is a serious departure from sustainable development goals [4]. The current disposal force, increasing the recycling of wasted concrete, plays a significant role in improving our ecological environment.

In order to improve the reuse of construction waste, many countries have carried out in-depth research on the mechanical properties of recycled aggregate concrete (RAC). RAC is a sort of environment-friendly concrete which can be obtained by mixing the waste concrete with a certain amount of natural aggregate after crushing, processing, and sorting [5]. Recycling discarded concrete can effectively solve the problem of harmless treatment and alleviate the ecological pollution brought by the civil construction industry [6]. Kazmi et al. [7] illustrated that the mechanical characteristics of RAC significantly differ from ordinary concrete under the same mix ratio condition. Compared with ordinary concrete, the compressive strength and elastic modulus of RAC can be reduced by about

26% and 35% [7]. Therefore, the existing prediction models for the compressive strength and elastic modulus calculation of ordinary concrete cannot accurately predict the related properties of RAC.

Previous research on the mechanical properties prediction of RAC is usually based on several groups of data measured in experiments or a large number of databases established to fit linear or nonlinear regression prediction formulas [8,9]. It is evident that the equation fitted from the experimental results requires a tedious experimental process and is often restricted by limited data. In addition, the mathematical theoretical derivation of the database is subject to inherent errors due to the simplified approximation of the correlation among complex parameters. Therefore, with the rapid development of modern computer technology, various machine learning techniques with higher prediction accuracy are widely used to analyze and predict the properties of RAC.

Hou and Zhou [10] used machine learning algorithms, such as Gaussian process regression and Radia Basis Function (RBF) neural network, to establish a prediction model for rectangular concrete-filled steel tubular columns' bias-bearing capacity. They verified that the results from the machine learning are more accurate than the norm and original formula [10]. Liu [11] predicted the properties of ordinary homemade concrete in tunnel engineering through five kinds of machine learning, including the decision tree and integrated learning. The maximum relative error of the outcomes is controlled within 10% [11]. In addition, various artificial neural network algorithm models, including random forest, correlation vector machine, reference model, BP neural network, and multi-layer neural network, have also been applied to predict the performance on compressive strength of the RAC [12–15]. It provides a reliable basis for allocating RAC according to the requirements of actual projects. However, since the realization of machine learning depends on the continuous debugging of hyperparameters in machine learning models and algorithm preprocessing by professionals, the period of model training and deployment is forced to be prolonged with the high professional requirements for users. The existing machine learning framework needs to carry out many algorithm combination selections and hyperparameter optimization to determine the model used and its corresponding hyperparameters from a mass of models. Due to the high workload and resource requirements for machine learning model training, it is difficult for non-professional users to apply this technology [9,16]. In this case, the invention of automatic machine learning (AutoML) realizes the complete automation of the machine learning process, which can not only effectively reduce the requirement for professional knowledge, but also significantly improve the availability and convenience of machine learning methods.

Among various machine learning platforms, AG, an open-source automatic machine learning framework developed by Amazon, is selected as the technical basis in this study to establish a high-precision performance prediction model for RAC. This paper first introduces the AG framework and its corresponding model training process. Then, based on the existing literature collection, the experimental data set of RAC is established, and the model training is carried out. After comparing the results of the traditional empirical formula and classical multivariate linear regression with that of AG, the practicability and superiority of the AG model are verified and analyzed.

2. AutoGluon Technology

2.1. Introduction and Advantages of AutoGluon

AutoML is a subfield in machine learning. It effectively combines the advantages of automation and machine learning. Users can deploy machine learning programs and then effectively verify and test the performance of the deployed program [17]. Based on this platform, users only need to develop their data set, and there is no need to learn deeply about the detail of machine learning models. An automatic machine learning platform can deal with whole steps, including data pre-processing, automatic feature selection (data normalization), auto algorithm choice, hyperparameter optimization (e.g., grid search, random searching, Bayesian optimization), auto pipeline development, neural architecture search, auto model choice, and ensemble learning to decide on the best model.

AG is an open-source AutoML frame developed by Erickson et al. in 2020 [9]. As a machine learning platform, compared with the traditional AutoML platform or artificial intelligence, the most outstanding advantage of AG is to avoid vast works for model choice and hyperparameter optimization process of the existing AutoML platform. It also shows a high prediction accuracy based on an original unpretreated database [18]. During the usage of AG, there is no need to learn about the running principle, even the content of the data set; users can use the data set directly and easily. Meanwhile, AG can deal with various kinds of structural data. If the preset training model does not match the original data set, AG has enough ability to solve the problems by itself, without intervention and choice from humans. In addition, it can not only take a high-level data treatment, deep learning, and multi-layer model integration but also automatically identify the data category in each column to measure those data, including the particular measurement of the text field. AG can also automatically optimize the AutoML processes like model network intelligence. Stopping or renewing the training process is another function of AG. Users can determine the training time required for the learning process and return the training results in time to provide the adjustment convenience based on the demand from users [9]. In short, this new AutoGluon AutoML platform simplifies the complex working process of AutoML, which means it decreases the professional requirement of the users to make more researchers could use the AutoML method to help with the studies. Those users could run the AutoML process without those difficult coding processes; the AutoML algorithm functions could be implemented within several lines of code, which is almost no impede to use the modern algorithm tools [19].

2.2. AutoGluon-Based Model Training

The regression and classification problem of table data is the essence of the prediction of RAC compressive strength and elastic modulus. This study uses AutoGluon Tabular, a framework for the prediction of tabular data in AG, to automatically classify the problem types and data regression based on the structural data in the comma-separated values format files [20]. There are various algorithms provided by AG frames, including the Neural Networks algorithm, the Machine Learning algorithm, which contains the Random Forest algorithm and Extreme Random Trees algorithm, the K-nearest Neighbors algorithm, and two types of Boosting Tree algorithm which are CatBoost and LightGBM. AG also covers integrated learning algorithms to improve prediction accuracy [20]. AG users can specify specific machine learning models for model training and model optimization [21].

Different from traditional machine learning, which only selects a single model for training, the output result of AG is integrated by combining multiple models. The results of the data prediction project show that AG performs better than any single training model in its training process [9]. As shown in Figure 1, the single model in the base firstly trains the input parameters. Then the prediction results are concentrated together and delivered to the next training level with several stacks to retrain. In the final layer, the model integrates the predictions of each model in the stack based on the weights [9]. AG combines the pre-built machine learning models through a multi-layer stack (typically 1 to 3 layers) and outputs them as a new fusion model. Meanwhile, AG reduces the prediction error with the help of the k-rule bootstrap aggregation algorithm (the value of k is usually 5 to 10), which optimizes the prediction model [18]. During model fusion and optimization, users can also set the value of stacking levels and the value of ‘k’. AG will automatically choose the suitable value if there is no specialized setting value [18]. The advantages of multi-layer stack and k-rule guided aggregation algorithms are not only in model fusion and model enhancement but also in avoiding the overfitting problem caused by the original data or the model itself during the machine learning process. Therefore, AG effectively improves the superior performance of the fusion models obtained from AutoML training in prediction scenarios in many ways.

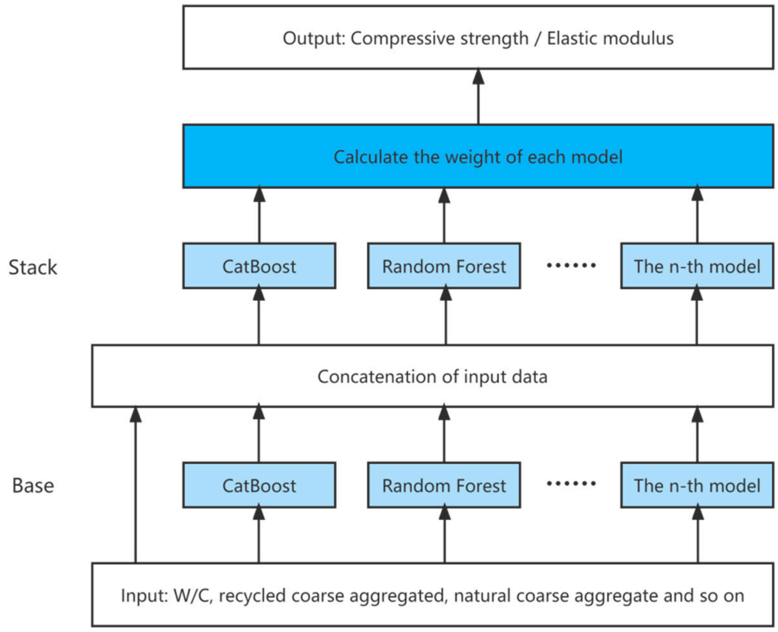


Figure 1. AG's multi-layer stacking strategy [14].

3. Data Collection and Evaluation Indicators

3.1. Data Collection

In construction engineering, compressive strength and elastic modulus are critical mechanical properties of concrete, which are usually used to evaluate and control the performance and quality of all kinds of mixed concrete [22]. Currently, the compressive strength and elastic modulus of RAC worldwide are primarily obtained through experiments. The experimental data show that the compressive strength, elastic modulus, and various engineering characteristics of RAC are mainly related to various factors, including the consumption of water, cement, natural aggregate, recycled aggregate, water-reducing agent, additional water, and ultra-fine additives, such as silica fume and fly ash [23]. In order to use AG to train and evaluate the compressive strength and the elastic modulus of RAC, an extensive literature survey was first conducted. We collected 842 groups of mix design and its corresponding compressive strength data and 430 groups of mix design and its corresponding elastic modulus data of RAC concrete from experimental data of 84 literatures, then the impact parameters common to different literatures were extracted and then established into two relevant databases, the specific literatures and corresponding data are listed in Appendices A and B. Among them, the contents of water, cement, natural coarse aggregate, fine natural aggregate, recycled coarse aggregate, fly ash, silica fume, and water-reducing agent per cubic meter of RAC are selected as the input parameters during the prediction process in the AutoML. The corresponding compressive strength and elastic modulus are selected as output parameters. For the experimental data of compressive strength of RAC, the experimental water content ranges from 116 kg to 271 kg, the amount of cement ranges from 190 kg to 667 kg, the amount of natural coarse aggregate and natural fine aggregate ranges from 0 kg to 1376 kg and 0 kg to 1020 kg, respectively. The amount of recycled coarse aggregate is between 0 kg and 1292 kg. Fly ash, water reducing agent dosage range of 0–234 kg, 0–9.9 kg. The output parameter compressive strength ranges from 17.29 MPa to 80.4 MPa. The statistical information of all features in the database is shown in Table 1. For the experimental data of elastic modulus of RAC, the experimental water content is between 94 kg and 246 kg, and the amount of cement is between 184.5 kg and 546 kg. The amounts of natural coarse aggregate and natural fine aggregate range from 0 kg to 1278 kg and 465 kg to 1073.43 kg, respectively. The amount of recycled coarse aggregate ranges from 0 kg to 1278 kg. Fly ash, silica fume, water reducing agent dosage range of 0–225.5 kg, 0 kg to 38 kg, 0–7.1 kg. The output parameter elastic modulus ranges from 3.67 GPa to 44.9 GPa. The statistics of all features in the database are shown in Table 2.

Table 1. Characteristic of RAC compressive strength parameter.

Type	Variable	Max	Min	Median	Mean	Standard Deviation
Input Value	water [kg]	271.00	116.00	185.49	189.90	23.25
	cement [kg]	667.00	190.00	386.50	393.36	74.48
	natural fine aggregate [kg]	1020.00	0.00	648.00	647.35	126.76
	natural coarse aggregate [kg]	1376.00	0.00	787.50	679.37	363.74
	recycled coarse aggregate [kg]	1292.00	0.00	313.00	417.09	354.19
	water reducer [kg]	9.90	0.00	0.00	0.40	1.41
	silicon ash [kg]	0.00	0.00	0.00	0.00	0.00
	fly ash [kg]	234.00	0.00	0.00	6.66	27.96
Output value	compressive strength [MPa]	80.40	17.29	40.80	41.19	10.56

Table 2. Characteristic of RAC elastic modulus parameter.

Type	Variable	Max	Min	Median	Mean	Standard Deviation
Input Value	water [kg]	246.00	94.00	200.00	190.79	30.61
	cement [kg]	546.00	184.50	373.00	378.62	83.71
	natural fine aggregate [kg]	1073.43	465.00	644.00	663.06	110.08
	natural coarse aggregate [kg]	1278.00	0.00	588.00	572.92	411.40
	recycled coarse aggregate [kg]	1278.00	0.00	469.41	501.23	419.42
	water reducer [kg]	7.10	0.00	0.00	1.10	2.08
	silicon ash [kg]	38.00	0.00	0.00	0.27	3.16
	fly ash [kg]	225.50	0.00	0.00	26.11	47.47
Output value	elastic modulus [GPa]	44.90	3.67	28.11	27.92	7.30

The original data are randomly divided into training and test sets. The training set is used to train the model, and the test set is used to evaluate the effectiveness of the trained model but does not change the model parameters and effects. If the training set is too large or too small, the accuracy of the training model will be affected. Besides, when the order of magnitudes of data is within ten thousand, the corresponding data sets are divided into 7:3, and there is no interaction between the training set and the test set. For the subdatabase of compressive strength, the training set includes 603 groups, and the test set includes 239 groups. For the subdatabase of elastic modulus, the training set includes 353 groups, and the test set includes 77 groups. The AutoGluon Tabular function based on tabular data prediction in AG is used to predict RAC's compressive strength and elastic modulus.

3.2. Evaluation Criteria

This study uses the following statistical parameters to evaluate the predictive performance of automatic machine-learning techniques for compressive strength and elastic modulus of RAC. These include mean absolute error (*MAE*), root mean square error (*RMSE*), mean absolute percentage error (*MAPE*), and coefficient of determination (R^2), where m represents the total number of related parameter samples of RAC, $\overline{X}$ represents the average value of the compressive strength or elastic modulus of recycled aggregate concrete, X

represents the experimental value of the compressive strength or elastic modulus of RAC, Y represents the predicted compressive strength or elastic modulus of RAC.

Mean absolute error (MAE) is the average of the absolute value difference between a single physical quantity and the arithmetic mean, which can represent the error well. The expression is as follows.

$$MAE = \frac{1}{m}\sum_{i=1}^{m}|Y - X| \quad (1)$$

Root mean square error ($RMSE$) is a statistical index to measure the accuracy of the forecast. The smaller the value, the higher the accuracy. The expression is as follows.

$$RMSE = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(Y - X)^2} \quad (2)$$

Mean absolute percentage error ($MAPE$) measures the relative size of deviation between the actual value of the sample and the predicted value, which is expressed by percentage. A small value indicates a slight deviation. The expression is as follows.

$$MAPE(\%) = \frac{1}{m}\sum_{i=1}^{m}\left|\frac{Y - X}{X}\right| * 100 \quad (3)$$

The determination coefficient (R^2) unifies the data dimension and can describe the overall regression trend. The closer the value is to 1, the better the regression performance of the model is. It can be expressed as:

$$R^2 = 1 - \frac{\sum_{i=1}^{m}(Y - X)^2}{(X - \overline{X})^2} \quad (4)$$

This study uses R^2 as an evaluation standard to intuitively show the prediction accuracy of compressive strength and elastic modulus of RAC.

4. Results and Discussion

4.1. Predictions Based on AutoML Models of AG

Figure 2 shows the prediction results of the compressive strength of RAC by using nine machine-learning models and one integrated model. Table 3 lists the evaluation indicators R^2, MAE, $RMSE$, and $MAPE$ for each model on the training and test data sets. Among these, 70 percent of the compressive strength data of RAC are used to train ten models, and the corresponding evaluation parameters and the best model with the highest accuracy are automatically presented. The remaining 30 percent of the data are used to verify the accuracy of trained models and present the evaluation parameters compared with real experimental data. In the test sets of the nine machine learning models, the models CatBoost, LightGBMXT, LightGBM, and ExtreTreeMSE exhibit high prediction accuracy with R^2 of 0.847, 0.829, 0.822, 0.821, MAE of 2.064, 2.417, 2.428, 2.148, $RMSE$ of 3.738, 3.951, 4.008, 4.043, and $MAPE$ of 6.291, 7.174, 7.289, 6.372, respectively. In comparison, the best-trained model, WeightedEnsemble, integrates the results of several models and, thus, has the highest prediction accuracy in testing results with evaluation parameters of 0.845, 2.100, 3.757, and 6.402, respectively. The results demonstrate that the compressive strength of RAC predicted by the model WeightedEnsemble is closest to the actual experimental values, and the prediction results show a higher evaluation index.

Figure 3 shows the elastic modulus prediction results of nine machine learning models and one integrated model about RAC. As same as the compressive strength of RAC, 70 percent of the elastic modulus data are used to train ten models, and the remaining 30 percent of data are used to verify the accuracy of trained models and present the evaluation parameters compared with real experimental data. Its corresponding evaluation indicators R^2, MAE, $RMSE$, and $MAPE$ are listed in Table 4, where R^2 is 0.962, 0.958, 0.947, 0.912, *MAE* is 0.889, 0.967, 1.082, 1.381, *RMSE* is 1.454, 1.523, 1.716, 2.219, *MAPE* is 1.454, 1.523, 1.716, 2.219. Similarly, the evaluation indicators of the model WeightedEnsemble are 0.957, 0.900, 1.546, and 5.073, which best predict the elastic modulus of RAC with the higher prediction accuracy.

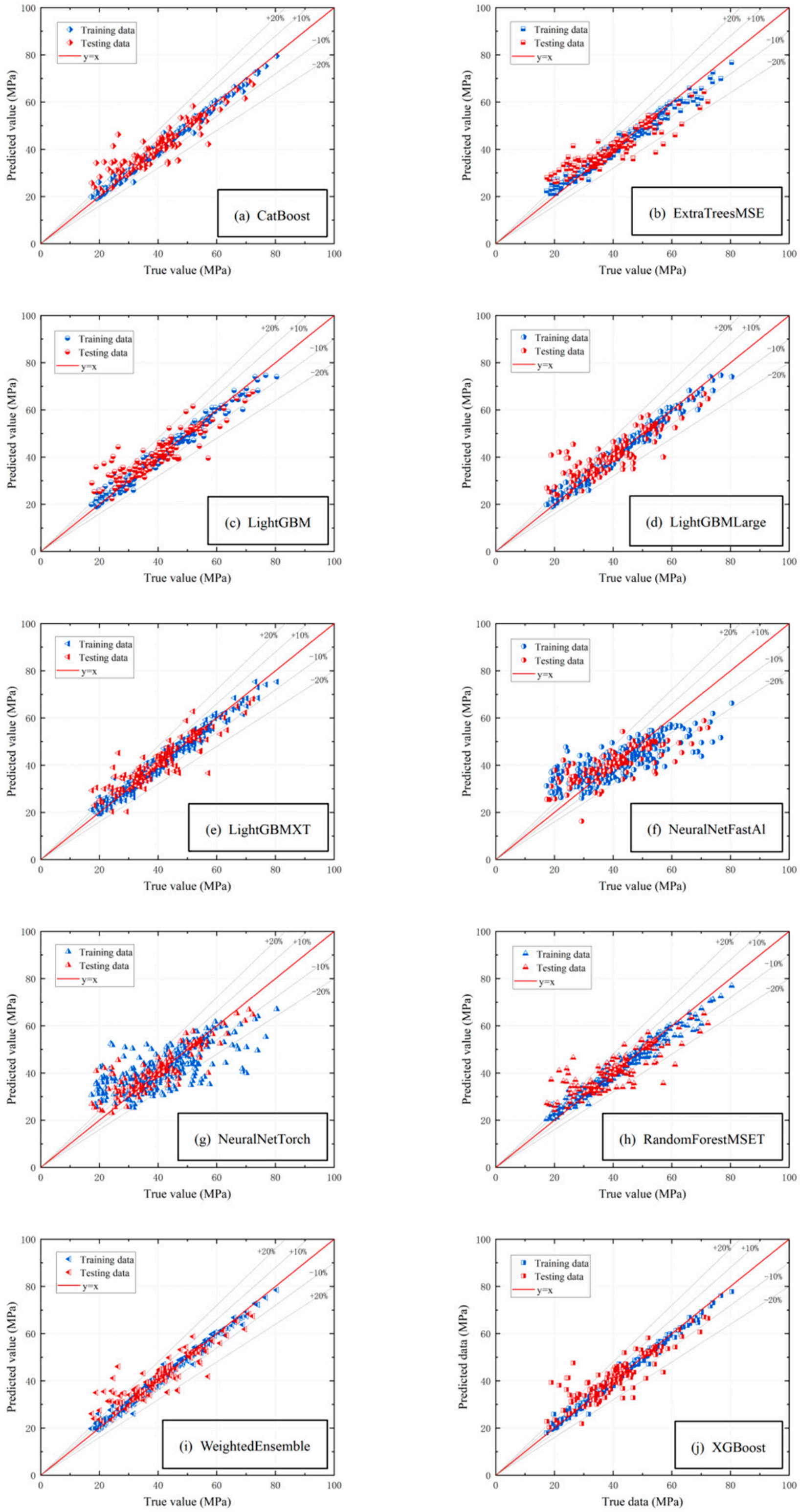


Figure 2. Compressive strength prediction model for RAC based on AG.

Table 3. Evaluation parameters for compressive strength of RAC.

Model	Evaluation Parameter							
	R^2		*MAE*		*RMSE*		*MAPE*	
	Training Results	**Testing Results**	**Training Results**	**Testing Results**	**Training Results**	**Testing Results**	**Training Results**	**Testing Results**
CatBoost	0.875	0.847	2.104	2.064	3.768	3.738	5.800	6.291
XGBoost	0.844	0.802	2.440	2.425	4.222	4.253	6.572	7.210
WeightedEnsemble	0.877	0.845	2.090	2.100	3.736	3.757	5.748	6.402
LightGBMLarge	0.845	0.786	2.374	2.463	4.193	4.420	6.365	7.511
RandomForestMSE	0.799	0.735	2.715	2.795	4.782	4.921	7.400	8.181
LightGBM	0.855	0.822	2.403	2.428	4.040	4.008	6.568	7.290
ExtraTreeMSE	0.815	0.821	2.576	2.148	4.597	4.043	7.283	6.372
LightGBMXT	0.835	0.829	2.590	2.417	4.329	3.951	7.348	7.174
NeuralNetTorch	0.574	0.661	4.262	3.253	6.970	5.572	11.903	8.956
NeuralNetFastAI	0.560	0.631	4.677	3.736	7.083	5.816	14.216	11.266

Table 4. Evaluation parameters for elastic modulus of RAC.

Model	Evaluation Parameter							
	R^2		*MAE*		*RMSE*		*MAPE*	
	Training Results	**Testing Results**	**Training Results**	**Testing results**	**Training Results**	**Testing Results**	**Training Results**	**Testing Results**
CatBoost	0.816	0.962	2.153	0.889	3.114	1.454	9.833	4.958
XGBoost	0.768	0.958	2.276	0.967	3.496	1.533	11.964	5.618
WeightedEnsemble	0.818	0.957	2.150	0.900	3.101	1.546	9.817	5.073
LightGBMLarge	0.765	0.947	2.417	1.082	3.509	1.716	11.210	6.759
RandomForestMSE	0.706	0.912	2.685	1.381	3.935	2.219	14.173	9.184
LightGBM	0.771	0.911	2.397	1.156	3.467	2.270	10.959	6.846
ExtraTreeMSE	0.634	0.910	2.940	1.420	4.395	2.247	17.016	9.316
LightGBMXT	0.740	0.858	2.533	1.556	3.631	2.359	12.614	9.402
NeuralNetTorch	0.506	0.540	3.191	2.576	5.107	5.070	20.875	20.106
NeuralNetFastAI	0.204	0.507	3.682	3.315	5.407	5.210	21.691	21.181

4.2. Comparison with Existing Empirical Formulas

In this study, we selected the empirical equations obtained from the study of Gholampour et al. [24] for the prediction of the compressive strength and elastic modulus of RAC. The empirical equations are as follows.

$$f'_{c,cube}(MPa) = \frac{19.1 * 0.998^{RCA\%} * \left(w_{eff}/c + 0.33\right)}{\left(w_{eff}/c\right)^{1.5}} \quad (5)$$

$$E_c(GPA) = 16 * (6.1 - 0.015r) * \left(5.3 - \frac{1.7w_{eff}}{c}\right)^{3.9} \quad (6)$$

where $f'_{c,cube}$ denotes the predicted compressive strength of RAC, E_c denotes the predicted elastic modulus of RAC, *RCA%* denotes the replacement rate of coarse aggregate in recycled aggregate concrete in percentage, w_{eff}/c denotes the effective water–cement ratio in the design of RAC mix.

The corresponding values from the database in this study are substituted into this formula to calculate the compressive strength and elastic modulus of RAC. The calculated results are compared with the actual experimental data provided in the available database. Figure 4 shows the predicted results of this empirical formula. For the compressive strength of RAC, the evaluation index is about 0.103 for R^2, 7.819 for *MAE*, 9.919 for *RMSE*, and 21.759 for *MAPE*, the evaluation index of elastic modulus R^2 is about 0.030, *MAE* is about 6.212, *RMSE* is about 8.497, and *MAPE* is about 35.546. Tables 5 and 6 present the evaluation indicators of the empirical formula on the compressive strength and elastic modulus of RAC, respectively. Compared with the empirical formula, the evaluation indicators of the WeightedEnsemble model for the compressive strength, R^2, *MAE*, *RMSE* and *MAPE*, are relatively 88% higher, 73% lower, 62% lower and 71% lower, respectively. The evaluation indicators for the elastic modulus, R^2, *MAE*, *RMSE* and *MAPE* are 97% higher, 86% lower, 82% lower and 86% lower, respectively. The results show that the AutoML model based on AG has significant advantages.

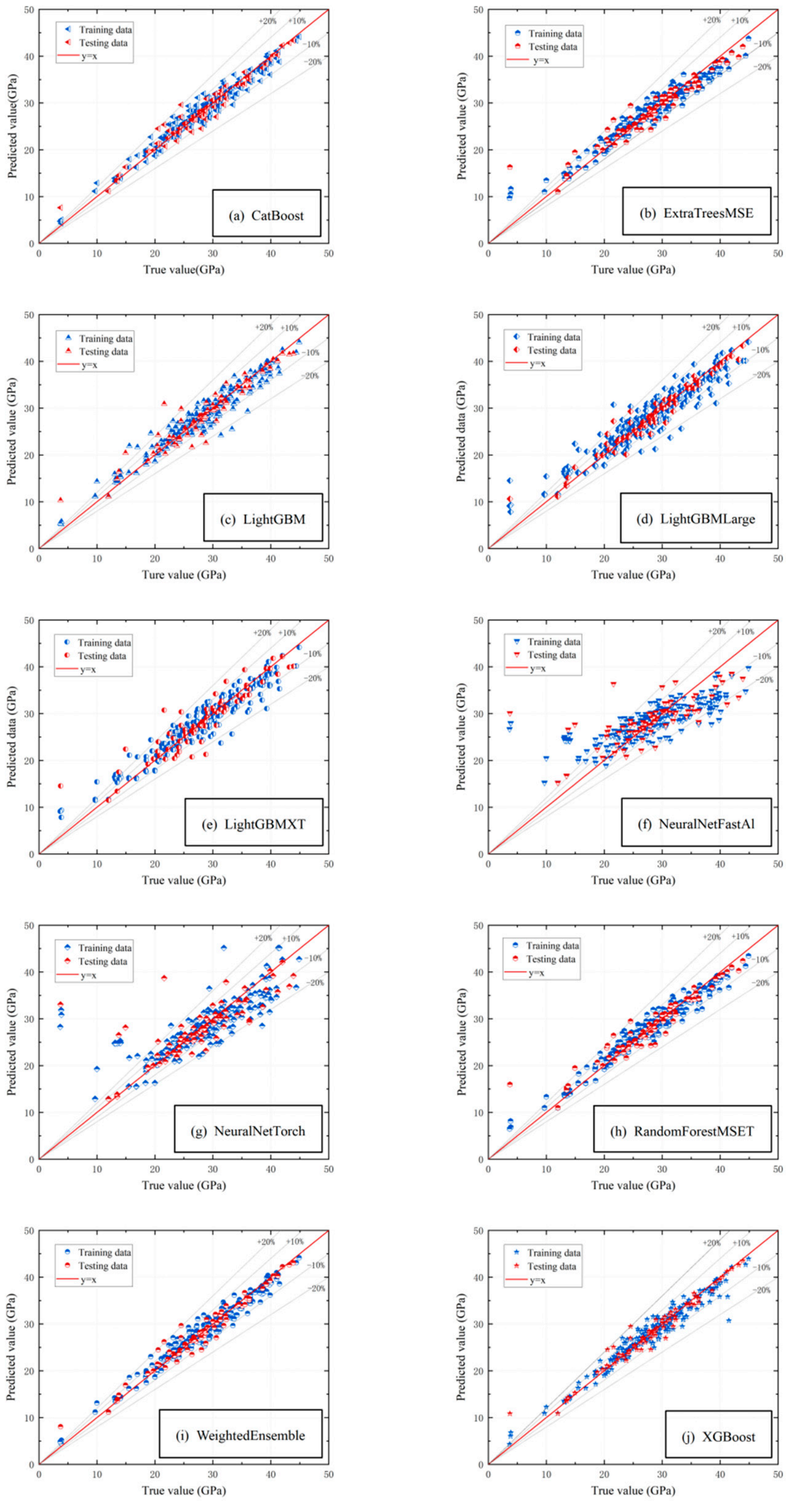
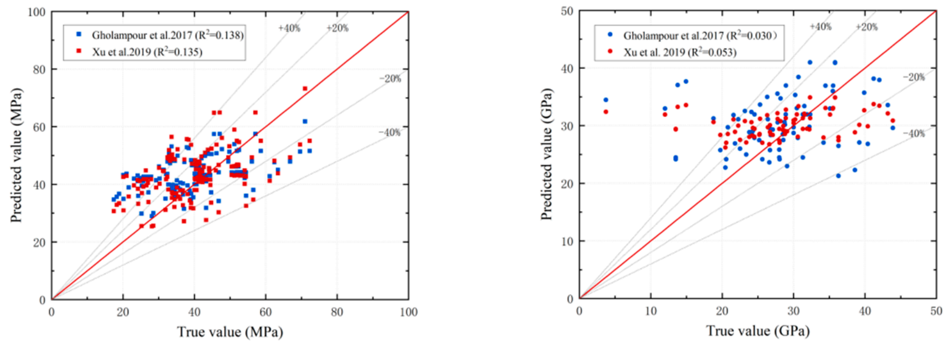


Figure 3. Elastic modulus prediction model for RAC based on AG.



(**a**) (**b**)

Figure 4. Comparison of conventional formulas for predicting compressive strength and elastic modulus of RAC. (**a**) Compressive strength; (**b**) Elastic modulus.

Table 5. Comparison of the traditional formula for compressive strength of RAC, multiple linear regression model and WeightedEnsemble model.

Model	Evaluation Indicator			
	R^2	*MAE*	*RMSE*	*MAPE*
Gholampour et al. (2017) [24]	0.103	7.819	9.919	21.759
Xu et al. (2019) [25]	0.135	7.807	9.689	22.174
Linear regression model	0.209	6.320	8.489	17.809
WeightedEnsemble	0.845	2.100	3.757	6.402

Table 6. Comparison of the traditional formula for the elastic modulus of RAC, multiple linear regression model and WeightedEnsemble model.

Model	Evaluation Indicator			
	R^2	*MAE*	*RMSE*	*MAPE*
Gholampour et al. (2017) [24]	0.030	6.212	8.497	35.546
Xu et al. (2019) [25]	0.053	5.374	7.597	32.359
Linear regression model	0.311	4.473	6.164	25.843
WeightedEnsemble	0.957	0.899	1.546	5.073

The empirical equations obtained from the study of Xu et al. [25] are selected for the prediction of compressive strength and elastic modulus of RAC. The empirical equations are as follows.

$$f'_{c,cube}(MPa) = \frac{28.97 - 4.71 * r^{1.69}}{\left(w_{eff}/c\right)^{0.63}} \tag{7}$$

$$E_c(GPa) = \frac{26836.23 - 5477.29 * r^{1.14}}{\left(w_{eff}/c\right)^{0.25}} \tag{8}$$

where $f'_{c,cube}$ denotes the predicted compressive strength of RAC, E_c denotes the predicted elastic modulus of RAC, r indicates the replacement rate of coarse aggregate in RAC in percentage, w_{eff}/c indicates the effective water–cement ratio in the design of RAC mix.

Plug the corresponding values into the above formula in the same way to obtain the calculated results of compressive strength and elastic modulus of RAC. The results are compared with the experimental data in the database. Figure 4 shows the prediction results of the empirical formula. The evaluation indicators R^2, *MAE*, *RMSE* and *MAPE* of compressive strength are about 0.135, 7.807, 9.689 and 22.174, respectively. The evaluation indicators of elastic modulus, *MAE*, *RMSE* and *MAPE* are 5.374, 7.594 and 32.359, respectively, while R^2 is only 0.053. Table 6 presents the specific evaluation indicators of this empirical formula. Compared with the prediction results, the evaluation index of the WeightedEnsemble model for compressive strength prediction R^2, *MAE*, *RMSE* and *MAPE* are relatively 84% higher, 73% lower, 61% lower and 74% lower, respectively. For the predicted elastic modulus, R^2, *MAE*, *RMSE* and *MAPE* are 93% higher, 60% lower, 59% lower and 65% lower, respectively. Therefore, the AG-based AutoML model has an obvious advantage over the above formulas, which7 exhibits higher prediction accuracy.

4.3. Comparison of Multiple Linear Regression Models Based on SPSS Software

In addition to the published empirical formulas of existing studies, this paper also uses the classical linear regression analysis software SPSS to analyze the compressive strength and the elastic modulus of RAC. Through multiple linear regression analysis, we obtain the accuracy of the fit on the original database. Then the results are compared with the experimental compressive strength and elastic modulus of RAC in the database. The regression prediction results of 30 percent of compressive strength and elastic modulus data are shown in Figure 5. In addition, the evaluation indicators of the prediction results on compressive strength and elastic modulus obtained from the multiple linear regression are shown in Tables 5 and 6, respectively. The evaluation indicators of the compressive strength of RAC R^2, *MAE*, *RMSE*, and *MAPE* are about 0.209, 6.320, 8.489 and 17.809, respectively. The evaluation indicators of the elastic modulus R^2, *MAE*, *RMSE* and *MAPE* are about 0.311, 4.473, 6.164 and 25.843, respectively. It can be seen that the prediction accuracy of SPSS-based multiple linear regression fitting is significantly improved compared with the existing empirical formulas provided in the previous section. However, it is still at a low accuracy level compared with the prediction accuracy of the WeightedEnsemble model in AG, which may not be effectively used in practical applications.

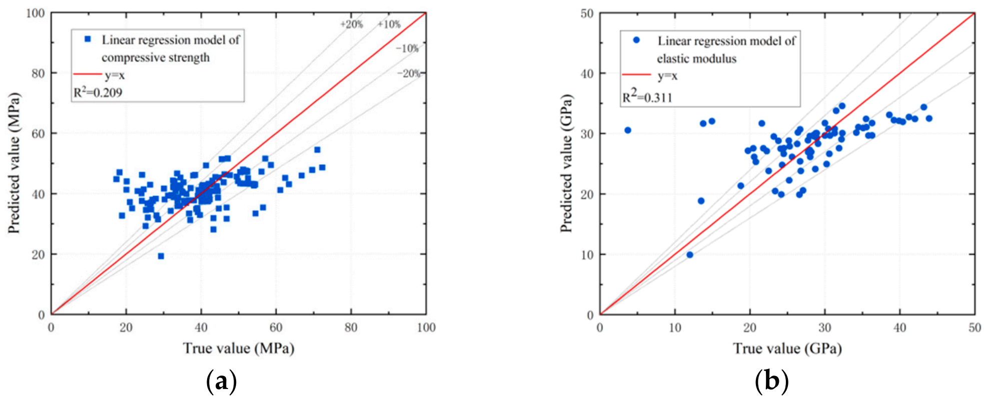


Figure 5. Multiple linear regression model of compressive strength and elastic modulus of RAC based on SPSS. (**a**) Compressive strength; (**b**) Elastic modulus.

4.4. The Compressive Strength and Elastic Modulus of Traditional Conversion Formulas

Compressive strength and elastic modulus are two typical mechanical characteristics when considering the mechanical performance of concretes. While compressive strength is the resistance ability of compression forces of a specimen, the elastic modulus could be defined as the relationship between the strain and stress caused by the load acting on the specimen [26,27]. It could be found that these two factors are both directly related to loading conditions and specimens responding to those loads; it is possible to determine the relationship between compressive strength and elastic modulus to make a conversion between them. In specific, when the acting loading reaches the compressive strength of a specimen, there would be a corresponding strain and stress at this specific condition, and the conversion relationship is possible to be determined. According to the literature review, amounts of researchers have published their regression equation to convert the compressive strength to elastic modulus in their studies. In general, these study results show that while the increment of concrete strength of concrete, the elastic modulus of concrete will also increase [28–30]. When only considering the compressive strength as the variable in the conversion equation, there is a group of the equation that has a similar general form shown as $E_c = \alpha f_c^{\beta} + \gamma$, which also fits with Equation (11) in the below discussion [30]. In addition, there are also a lot of variable parameters which is related to the proportion of the concrete mixture design for the content of different materials considered in the conversion equations to make the conversion results could fit the realistic better [28–30].

In this study, some conversion equations are selected by a literature review to compare and contrast with the performance of the AutoML model based on AG. The data containing both the compressive strength and elastic modulus of RAC are extracted from the original total database and established as a separate database. A set of elastic modulus data is obtained by AG prediction. The other sets of elastic modulus data are obtained by the traditional conversion formula between compressive strength and elastic modulus. Figure 6 shows the prediction results between the conversion formulas and the predictions of AG. Table 7 lists the corresponding statistical parameters. The conventional conversion equations involved are as follows, where E_c denotes the predicted elastic modulus of RAC, and $f'_{c,cube}$ denotes the predicted compressive strength of recycled aggregate concrete.

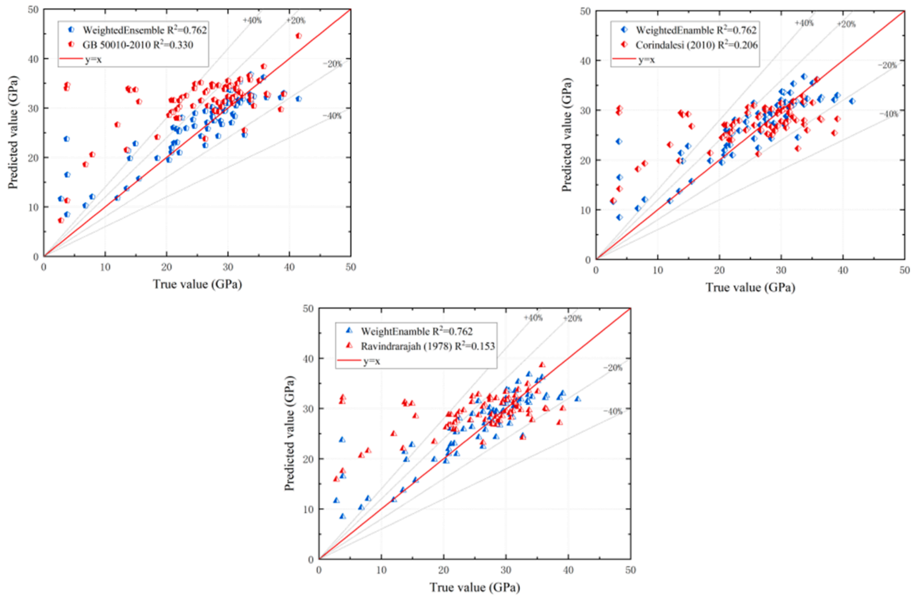


Figure 6. Prediction results of traditional conversion formula and WeightedEnsemble model in RAC's compressive strength and elastic modulus.

GB 50010-2010 [31]:

$$E_c = \frac{10^5}{2.2 + 34.7/f'_{c,cube}} \tag{9}$$

Corindalesi (2010) [32]:

$$E_c = \frac{26836.23 - 5477.29 \ * \ r^{1.14}}{\left(w_{eff}/c\right)^{0.25}} \tag{10}$$

Ravindrarajah (1978) [33]:

$$E_c = 3.02 {f'_{c,cube}}^{0.50} + 10.67 \tag{11}$$

From Table 7, the statistical parameter R^2 of the elastic modulus predicted by AG is 0.734, *MAE* is 3.051, *RMSE* is 4.420, and *MAPE* is 27.307. Whereas the statistical parameters of the traditional conversion formula R^2 ranges from 0.153–0.330, *MAE* ranges from 5.563–6.514, *RMSE* ranges from 8.286–10.420, and *MAPE* ranges from 48.051–55.527.

Through comparison, the WeightedEnsemble model has better evaluation indexes, which are better than the results of any of the conversion formulas. The results show AG still has a higher accuracy in predicting the elastic modulus than using the conversion formulas, which reflects its significant advantage and applicability.

Table 7. Evaluation parameters for prediction results of traditional conversion formula and Weighted Ensemble model in RAC's compressive strength and elastic modulus.

Experience Formula	Statistical Parameter			
	R^2	*MAE*	*RMSE*	*MAPE*
GB 50010-2010	0.330	6.514	8.772	53.949
Corindalesi (2010) [32]	0.206	5.563	8.286	48.051
Ravindrarajah (1978) [33]	0.153	6.307	10.074	55.527
WeightedEnsemble	0.734	3.051	4.420	27.307

5. Conclusions

In conclusion, in order to determine an accurate prediction method for recycled aggregate concrete (RAC) compressive strength and elastic modulus, this study uses the AutoGluon-Tabular framework to do the auto-machine-learning based on two collected databases, which is based on a previous literature review, of compressive strength and elastic modulus, respectively. By considering multiple indexes of RAC, including the content of water, cement, natural coarse aggregate and recycled coarse aggregate, this study compares the prediction results of auto-machine-learning models with the model from the representative empirical formulas and the SPSS-based multiple linear regression model. The comparison results show that the AG models have the best performance among all alternative prediction methods in both fields of compressive strength and elastic modulus prediction. In addition, the study also tests the AG performance in the field of converting the compressive strength of RAC into elastic modulus. AG still has a significantly higher accuracy in the conversion work rather than conventional conversion formulas. Take the accuracy performance evaluation parameter R^2 as an instance, the R^2 value could increase by around 90% and 70% when predicting the compressive strength and elastic modulus compared with the traditional empirical formulas and multiple linear regression models, respectively. Although the conversion result is not good as the previous two fields, it still increases the accuracy by 55% under the consideration of evaluation parameter R^2. In specific, the best prediction model during the AG training and test is considered the WeightedEnsemble model.

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Abbreviations

The following abbreviations are used in this manuscript:

RAC	Recycled Aggregate Concrete
AG	AutoGluon
AutoML	Automatic Machine Learning

Appendix A

Recycled aggregate strength prediction concrete mix ratio data set [34–117].

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
1	184	340	656	1220	0	0	0	0	35.7
2	184	340	656	854	366	0	0	0	37.8
3	184	340	656	610	610	0	0	0	39.5
4	184	340	656	366	854	0	0	0	38.4
5	184	340	656	0	1220	0	0	0	39.1
6	184	340	656	610	610	0	0	0	39.8
7	184	306	656	610	610	0	0	0	39.1
8	184	272	656	610	610	0	0	0	36.9
9	184	238	656	610	610	0	0	0	33.7
10	184	340	656	1220	0	0	0	0	35.7
11	116	340	656	610	610	0	0	0	52.4
12	150	340	656	610	610	0	0	0	46.8
13	184	340	656	610	610	0	0	0	39.5
14	218	340	656	610	610	0	0	0	27.9
15	207	360	690	0	1140	0	0	0	38.2
16	198	360	700	0	1140	0	0	0	41.3
17	209	380	690	0	1120	0	0	0	41.8
18	199	380	690	0	1130	0	0	0	44.1
19	181	330	715	0	1175	0	0	0	33.5
20	185	430	555	1295	0	0	0	0	34.5
21	185	390	558	1301	0	0	0	0	31.3
22	214	667	362	1086	0	0	0	0	48.3
23	221	667	360	1080	0	0	0	0	40.2
24	209	666	364	1093	0	0	0	0	46
25	217	660	287	861	209	0	0	0	44.9
26	230	661	284	853	202	0	0	0	43.2
27	206	661	288	864	216	0	0	0	43
28	229	647	176	527	513	0	0	0	44.7
29	247	647	175	524	496	0	0	0	39.7
30	207	649	177	531	531	0	0	0	38.1
31	190	380	714	1004	0	0	0	0	45.25
32	190	380	744	757	189	0	0	0	47.4
33	190	380	710	471	471	0	0	0	47.3
34	190	380	715	0	874	0	0	0	54.8
35	190	380	714	1004	0	0	0	0	45.85
36	190	380	744	757	189	0	0	0	47.7
37	190	380	710	471	471	0	0	0	50.2
38	156	349	888	0	792	0	0	0	42
39	156	349	888	0	792	0	0	0	42.2
40	157	262	888	0	792	0	0	0	32.8
41	157	262	888	0	792	0	0	0	34.6
42	155	349	888	0	792	0	0	0	42
43	155	349	888	0	792	0	0	0	43
44	155	349	888	0	792	0	0	0	41
45	151	335	630	414	720	0	0	0	40.6
46	151	335	630	414	720	0	0	0	39.8
47	151	335	630	414	720	0	0	0	37.3

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
48	151	251	630	414	720	0	0	0	35.2
49	151	251	630	414	720	0	0	0	33.3
50	151	251	630	414	720	0	0	0	34.2
51	149	335	630	414	720	0	0	0	41.2
52	149	335	630	414	720	0	0	0	41.7
53	156	349	857	0	867	0	0	0	41.2
54	156	349	857	0	867	0	0	0	39.3
55	156	349	857	0	867	0	0	0	38.5
56	157	262	857	0	867	0	0	0	34.3
57	157	262	857	0	867	0	0	0	36.1
58	157	262	857	0	867	0	0	0	34.7
59	155	349	857	0	867	0	0	0	39.1
60	155	349	857	0	867	0	0	0	41.6
61	155	349	857	0	867	0	0	0	37.2
62	161	358	645	281	813	0	0	0	41
63	161	358	645	281	813	0	0	0	40.2
64	161	358	645	281	813	0	0	0	38.9
65	161	269	645	281	813	0	0	0	33
66	161	269	645	281	813	0	0	0	36.5
67	161	269	645	281	813	0	0	0	36.1
68	160	358	645	281	813	0	0	0	40.8
69	160	358	645	281	813	0	0	0	38.7
70	165	330	715	1084	0	0	0	0	51.2
71	176	320	708	1072	0	0	0	0	47.1
72	186	310	702	1064	0	0	0	0	43.9
73	140	350	732	553	523	0	0	0	46.1
74	153	340	715	547	517	0	0	0	45.8
75	165	330	708	541	511	0	0	0	39.9
76	176	320	702	535	506	0	0	0	36.3
77	186	310	892	531	501	0	0	0	34.7
78	225	450	892	1115	0	0	0	0	22
79	225	450	892	836	279	0	0	0	21.7
80	225	450	892	558	558	0	0	0	21.9
81	225	450	892	279	836	0	0	0	18.6
82	225	450	892	0	1115	0	0	0	18.9
83	225	432	892	1115	0	0	0	0	32.4
84	225	432	892	836	279	0	0	0	29.1
85	225	432	892	558	558	0	0	0	30.4
86	225	432	892	279	836	0	0	0	31.6
87	225	432	892	0	1115	0	0	0	30.5
88	225	414	892	1115	0	0	0	0	37.5
89	225	414	892	836	279	0	0	0	32.3
90	225	414	892	558	558	0	0	0	33.9
91	225	414	892	279	836	0	0	0	32
92	225	414	892	0	1115	0	0	0	31.7
93	225	396	892	1115	0	0	0	0	39
94	225	396	892	836	279	0	0	0	34.3
95	192	452	730	963	0	0	0	0	44.4
96	193	428	734	969	0	0	0	0	42.8
97	193	429	736	729	230	0	0	0	37.7
98	190	423	726	479	453	0	0	0	39.3
99	192	427	733	242	687	0	0	0	35.3
100	192	426	731	0	913	0	0	0	37.6
101	195	431	741	489	457	0	0	0	35.1
102	195	433	744	0	918	0	0	0	36.3
103	192	427	734	484	451	0	0	0	33.6
104	194	432	742	0	912	0	0	0	34.4

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
105	193	430	737	0	917	0	0	0	31.6
106	194	316	803	953	909	0	0	0	29.3
107	192	320	819	0	914	0	0	0	27.1
108	193	322	823	0	908	0	0	0	24.9
109	192	320	819	0	899	0	0	0	20.5
110	194	645	563	973	0	0	0	0	58.5
111	120	400	720	756	324	0	0	0	63.92
112	120	400	720	0	1080	0	0	0	49.19
113	140	400	720	1080	0	0	0	0	68.01
114	140	400	720	756	324	0	0	0	56.21
115	140	400	720	0	1080	0	0	0	46
116	180	400	720	1080	0	0	0	0	58.4
117	180	400	720	972	108	0	0	0	55.4
118	180	400	720	864	216	0	0	0	55.1
119	180	400	720	756	324	0	0	0	52.4
120	180	400	720	648	432	0	0	0	51.97
121	180	400	720	540	540	0	0	0	50
122	180	400	720	432	648	0	0	0	48
123	180	400	720	324	756	0	0	0	46.8
124	180	400	720	216	864	0	0	0	47.24
125	200	400	720	756	324	0	0	0	37.22
126	200	400	720	0	1080	0	0	0	32
127	220	400	720	1080	0	0	0	0	40
128	220	400	720	756	324	0	0	0	34.02
129	220	400	720	0	1080	0	0	0	29
130	240	400	720	1080	0	0	0	0	32.21
131	240	400	720	756	324	0	0	0	32.3
132	240	400	720	0	1080	0	0	0	25.26
133	180	600	720	1080	0	0	0	0	80.4
134	180	600	720	756	324	0	0	0	74.01
135	180	600	720	0	1080	0	0	0	55.46
136	180	514	720	1080	0	0	0	0	73.1
137	180	514	720	756	324	0	0	0	65.94
138	180	514	720	0	1080	0	0	0	51.82
139	180	450	720	1080	0	0	0	0	66.12
140	180	450	720	756	324	0	0	0	57.13
141	180	450	720	0	1080	0	0	0	45.62
142	180	360	720	1080	0	0	0	0	52.2
143	180	360	720	756	324	0	0	0	47.6
144	180	360	720	0	1080	0	0	0	34.35
145	180	327	720	1080	0	0	0	0	50.42
146	180	327	720	756	324	0	0	0	42.91
147	180	327	720	0	1080	0	0	0	32.3
148	180	300	720	1080	0	0	0	0	42.93
149	190	355	545	1270	0	0	0	0	29.58
150	190	355	545	826	445	0	0	0	27.27
151	190	355	545	635	635	0	0	0	25.27
152	230	430	535	806	806	0	0	0	26.9
153	230	430	535	620	620	0	0	0	24.2
154	230	430	535	434	806	0	0	0	22.5
155	225	410	642	1048	0	0	0	0	48.6
156	225	410	642	840	204	0	0	0	45.3
157	225	410	642	524	506	0	0	0	42.5
158	225	410	642	0	1017	0	0	0	38.1
159	225	308	611	1048	0	0	0	0	43.6
160	225	308	611	840	204	0	0	0	42.8
161	225	308	611	524	506	0	0	0	41.7

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
162	225	308	611	0	1017	0	0	0	36.8
163	225	267	598	1048	0	0	0	0	40.7
164	225	267	598	840	204	0	0	0	41
165	180	400	708	554	538	0	0	0	55.8
166	180	400	708	0	1075	0	0	0	42
167	180	300	688	1180	0	0	0	0	54.4
168	180	300	688	886	215	0	0	0	49.7
169	180	300	688	554	538	0	0	0	44.3
170	180	300	688	0	1075	0	0	0	39.5
171	180	260	688	1180	0	0	0	0	45.9
172	180	260	688	886	215	0	0	0	43.6
173	180	260	688	554	538	0	0	0	40.4
174	180	260	688	0	1075	0	0	0	38.3
175	225	410	642	1048	0	0	0	0	48.6
176	225	410	642	840	204	0	0	0	45.3
177	225	410	642	554	506	0	0	0	42.5
178	225	410	642	0	1017	0	0	0	38.1
179	225	384	582	992	0	0	0	0	52.9
180	225	384	582	794	193	0	0	0	50.1
181	225	384	582	496	482	0	0	0	48.1
182	225	384	582	0	963	0	0	0	45.3
183	225	360	598	1180	0	0	0	0	68.9
184	225	360	598	840	204	0	0	0	63
185	205	410	662	865	210	0	0	0	51.7
186	205	410	662	541	525	0	0	0	47.1
187	205	410	662	0	1049	0	0	0	43.4
188	205	384	618	1009	0	0	0	0	57.6
189	205	384	618	802	196	0	0	0	55.8
190	205	384	618	505	489	0	0	0	52.5
191	205	384	618	0	979	0	0	0	51.2
192	180	400	708	1108	0	0	0	0	66.8
193	180	400	708	886	215	0	0	0	62.4
194	180	400	708	554	538	0	0	0	56.8
195	180	400	708	0	1075	0	0	0	52.1
196	180	375	665	1040	0	0	0	0	70.1
197	180	375	665	802	202	0	0	0	67.3
198	160	400	729	570	554	0	0	0	65.3
199	160	400	729	0	1107	0	0	0	58.5
200	160	375	685	1071	0	0	0	0	76.7
201	160	375	685	214	208	0	0	0	73.9
202	160	375	685	536	520	0	0	0	70.1
203	160	375	685	0	1040	0	0	0	68.7
204	183	321	675	0	0	0	0	0	21
205	185	369	628	1218	0	0	0	0	29.7
206	185	369	628	914	305	0	0	0	29
207	185	369	628	609	609	0	0	0	28
208	180	419	586	1215	0	0	0	0	35
209	180	419	586	911	304	0	0	0	34.5
210	180	419	586	607	607	0	0	0	33.2
211	180	419	586	304	811	0	0	0	32.5
212	180	419	586	0	1215	0	0	0	31
213	214	353	667	1086	0	0	0	0	48.3
214	221	353	667	1080	0	0	0	0	40.2
215	209	353	666	1093	0	0	0	0	46
216	217	353	660	861	209	0	0	0	44.9
217	230	353	661	853	202	0	0	0	43.2
218	206	353	661	864	216	0	0	0	43

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
219	209	353	625	0	1026	0	0	0	39.1
220	173	432	714	1081	0	0	0	0	52.5
221	173	432	713	756	324	0	0	0	48.5
222	175	436	720	545	545	0	0	0	48.5
223	175	437	700	328	766	0	0	0	47
224	178	445	735	167	946	0	0	0	47.5
225	177	441	728	0	1104	0	0	0	47
226	189	474	523	1211	0	0	0	0	35.03
227	189	474	523	848	363	0	0	0	19.8
228	189	474	523	605	606	0	0	0	35.98
229	189	474	523	364	847	0	0	0	29.09
230	189	474	523	0	1211	0	0	0	21.48
231	189	420	523	1211	0	0	0	0	32.84
232	189	474	523	848	363	0	0	0	31.62
233	189	474	523	605	606	0	0	0	40.12
234	189	474	523	364	847	0	0	0	31.93
235	208	422	607	566	566	0	0	0	28
236	217	422	607	283	850	0	0	0	26.7
237	226	422	607	0	1129	0	0	0	25.6
238	180	327	683	1197	0	0	0	0	24.9
239	190	327	666	899	297	0	0	0	23.5
240	200	327	666	598	598	0	0	0	22.3
241	209	327	666	297	899	0	0	0	20.8
242	218	327	666	0	1197	0	0	0	20.3
243	155	390	890	950	0	0	0	0	44.09
244	155	390	890	240	660	0	0	0	41.05
245	155	390	890	925	0	0	0	0	36.08
246	155	390	890	230	650	0	0	0	38.02
247	155	390	890	890	0	0	0	0	44.5
248	155	390	890	220	620	0	0	0	42.43
249	167	235	1010	930	0	0	0	0	22.13
250	170	240	990	220	620	0	0	0	22.29
251	160	326	668	825	0	0	0	0	31.62
252	160	269	686	847	0	0	0	0	27.9
253	160	224	700	864	0	0	0	0	27.81
254	150	292	688	850	0	0	0	0	30.66
255	170	360	649	801	0	0	0	0	36.87
256	160	320	922	0	723	0	0	0	37.72
257	160	264	946	0	742	0	0	0	31.38
258	160	218	965	0	757	0	0	0	29.42
259	150	286	949	0	744	0	0	0	37.59
260	170	355	895	0	702	0	0	0	39.08
261	216.35	488.36	500	908	194	0	0	0	34.99
262	216.35	488.36	500	952	166	0	0	0	34.98
263	216.35	488.36	500	984	137	0	0	0	34.97
264	216.35	488.86	500	1003	120	0	0	0	34.97
265	216.35	488.86	500	1012	112	0	0	0	34.98
266	182.75	340.1	500	1166	184	0	0	0	31.87
267	182.75	340.1	500	1185	167	0	0	0	31.33
268	216.35	488.36	501	934	181	0	0	0	34.95
269	216.35	488.36	501	962	167	0	0	0	34.86
270	216.35	488.86	501	985	181	0	0	0	34.88
271	216.35	488.86	501	1013	156	0	0	0	34.89
272	216.35	489.35	501	1036	135	0	0	0	35
273	182.75	340.1	501	1167	110	0	0	0	31.83
274	182.75	340.1	501	1186	89	0	0	0	31.29
275	182.75	340.1	501	1195	182	0	0	0	31.06

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
276	216.35	488.36	502	916	165	0	0	0	34.94
277	216.35	488.36	502	935	157	0	0	0	34.85
278	216.35	488.36	502	963	196	0	0	0	34.76
279	216.35	488.86	502	986	179	0	0	0	34.79
280	216.35	488.86	502	995	154	0	0	0	34.79
281	216.35	488.86	502	1014	133	0	0	0	34.81
282	216.35	489.35	502	1046	125	0	0	0	34.95
283	182.75	340.1	502	1168	108	0	0	0	31.78
284	182.75	340.1	502	1196	155	0	0	0	31.03
285	216.35	488.36	503	917	194	0	0	0	34.84
286	216.35	488.36	503	945	169	0	0	0	34.71
287	216.35	488.36	503	964	152	0	0	0	34.66
288	216.35	488.86	503	996	123	0	0	0	34.7
289	216.35	488.86	503	1015	106	0	0	0	34.72
290	216.35	489.35	503	1028	94	0	0	0	34.81
291	216.35	489.35	503	1047	77	0	0	0	34.87
292	214.75	488.36	524	785	293	0	0	0	34.77
293	214.75	488.36	524	804	276	0	0	0	34.35
294	183.21	369.84	524	1161	136	0	0	0	31.67
295	183.21	369.84	524	1170	128	0	0	0	31.52
296	183.21	369.84	524	1189	111	0	0	0	31.24
297	183.21	369.84	524	1208	94	0	0	0	31.02
298	214.75	488.36	525	786	291	0	0	0	34.66
299	214.75	488.36	525	814	266	0	0	0	34.06
300	214.75	488.36	525	838	245	0	0	0	33.67
301	214.75	488.36	525	857	228	0	0	0	33.39
302	214.75	488.36	525	866	220	0	0	0	33.28
303	216.35	488.36	525	899	186	0	0	0	32.73
304	214.75	488.36	526	796	281	0	0	0	34.34
305	214.75	488.36	526	815	264	0	0	0	33.95
306	214.57	488.36	526	839	243	0	0	0	33.55
307	214.57	488.36	526	867	218	0	0	0	33.17
308	216.35	488.36	526	881	201	0	0	0	32.78
309	216.35	488.36	526	900	184	0	0	0	32.63
310	216.35	488.36	526	919	167	0	0	0	32.53
311	216.35	488.36	526	928	159	0	0	0	32.5
312	216.35	488.36	526	947	142	0	0	0	32.47
313	216.35	488.36	526	966	125	0	0	0	32.49
314	216.35	488.86	526	979	113	0	0	0	32.6
315	216.35	489.35	526	1002	92	0	0	0	32.78
316	216.35	489.35	526	1030	67	0	0	0	32.97
317	216.35	489.35	526	1049	50	0	0	0	33.14
318	210.42	489.35	526	1068	48	0	0	0	34.07
319	198.47	381.31	646	914	175	0	0	0	34.29
320	198.47	381.31	646	933	158	0	0	0	33.43
321	198.47	381.31	646	961	133	0	0	0	32.45
322	198.47	381.31	646	980	116	0	0	0	31.96
323	198.47	381.31	646	1008	91	0	0	0	31.46
324	198.47	381.31	646	1027	74	0	0	0	31.27
325	198.47	381.31	646	1055	49	0	0	0	31.14
326	192.54	381.31	646	1065	55	0	0	0	32.38
327	196.77	377.96	646	1073	40	0	0	0	31.43
328	196.77	375.41	646	1109	10	0	0	0	31.52
329	198.47	381.31	647	915	173	0	0	0	34.36
330	198.47	381.31	647	934	156	0	0	0	33.52
331	198.47	381.31	647	943	148	0	0	0	33.17
332	198.47	381.31	647	962	131	0	0	0	32.56

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
333	198.47	381.31	647	981	114	0	0	0	32.08
334	198.47	381.31	647	990	106	0	0	0	31.9
335	198.47	381.31	647	1009	89	0	0	0	31.61
336	198.47	381.31	647	1028	72	0	0	0	31.43
337	198.47	381.31	647	1037	64	0	0	0	31.37
338	198.47	381.31	647	1056	47	0	0	0	31.31
339	192.54	381.31	647	1066	53	0	0	0	32.55
340	196.77	377.96	647	1074	38	0	0	0	31.61
341	196.77	377.96	647	1083	30	0	0	0	31.6
342	196.77	375.41	647	1110	8	0	0	0	31.71
343	198.47	381.31	648	916	171	0	0	0	34.43
344	198.47	381.31	648	944	146	0	0	0	33.27
345	198.47	381.31	648	963	129	0	0	0	32.67
346	198.47	381.31	648	991	104	0	0	0	32.04
347	198.47	381.31	648	1010	87	0	0	0	31.76
348	198.47	381.31	648	1038	62	0	0	0	31.54
349	198.47	381.31	648	1057	45	0	0	0	31.49
350	192.54	381.31	648	1067	51	0	0	0	32.73
351	196.77	377.96	648	1084	28	0	0	0	31.78
352	196.77	375.41	648	1092	23	0	0	0	31.87
353	196.77	375.41	648	1111	6	0	0	0	31.9
354	198.47	381.31	649	917	169	0	0	0	34.5
355	198.47	381.31	649	926	161	0	0	0	34.1
356	198.47	381.31	649	945	144	0	0	0	33.37
357	195.83	374.66	646	790	327	0	0	0	45
358	195.83	374.66	646	807	293	0	0	0	43.58
359	178.19	337.22	650	859	317	0	0	0	44.94
360	178.19	337.22	650	868	309	0	0	0	44.55
361	178.19	337.22	650	877	301	0	0	0	44.16
362	178.19	337.22	650	887	292	0	0	0	43.71
363	178.19	337.22	650	896	284	0	0	0	43.3
364	178.19	337.22	650	906	275	0	0	0	42.85
365	178.19	337.22	650	915	267	0	0	0	42.43
366	178.19	337.22	650	924	259	0	0	0	42.02
367	178.19	337.22	650	934	250	0	0	0	41.55
368	178.19	337.22	650	943	242	0	0	0	41.14
369	178.19	337.22	650	953	233	0	0	0	40.68
370	208.81	428.6	500	502	649	0	0	0	41.82
371	208.81	428.6	500	512	640	0	0	0	41.81
372	208.81	428.6	500	521	632	0	0	0	41.79
373	208.81	428.6	500	531	623	0	0	0	41.75
374	208.81	428.6	500	540	615	0	0	0	41.7
375	209.4	484.75	500	541	567	0	0	0	41.4
376	211.49	428.6	500	547	602	0	0	0	41.64
377	208.81	428.6	500	549	607	0	0	0	41.65
378	209.4	484.75	500	551	558	0	0	0	41.33
379	211.49	428.6	500	556	594	0	0	0	41.56
380	209.4	484.75	500	560	550	0	0	0	41.25
381	211.49	428.6	500	566	585	0	0	0	41.46
382	211.49	428.6	500	575	577	0	0	0	41.36
383	215.33	484.75	500	578	519	0	0	0	40.71
384	215.2	359.75	601	1083	59	0	0	0	40.23
385	216.9	363.1	602	1037	92	0	0	0	40.13
386	216.9	363.1	602	1047	83	0	0	0	40.51
387	216.9	363.1	602	1056	75	0	0	0	40.82
388	215.2	359.75	602	1075	65	0	0	0	40.15
389	211.49	428.6	524	540	582	0	0	0	42.53

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
390	209.4	484.75	524	544	538	0	0	0	41.58
391	209.4	484.75	524	553	530	0	0	0	41.45
392	209.4	484.75	524	563	521	0	0	0	41.3
393	214.75	484.5	524	565	506	0	0	0	40.73
394	214.75	484.5	524	575	497	0	0	0	40.52
395	214.75	484.5	524	584	489	0	0	0	40.32
396	214.75	484.5	524	593	481	0	0	0	40.1
397	209.4	484.75	525	526	553	0	0	0	41.82
398	211.49	428.6	525	532	588	0	0	0	42.69
399	209.4	484.75	525	536	544	0	0	0	41.71
400	211.49	428.6	525	541	580	0	0	0	42.57
401	195.83	373.75	646	687	401	0	0	0	53.72
402	195.83	373.75	646	706	384	0	0	0	52.26
403	195.83	374.66	646	713	377	0	0	0	51.89
404	195.83	373.75	647	688	399	0	0	0	53.72
405	195.83	373.75	648	689	397	0	0	0	53.73
406	195.83	374.66	648	724	365	0	0	0	51.11
407	195.83	373.75	649	699	387	0	0	0	53.04
408	195.83	374.66	649	725	363	0	0	0	51.1
409	185.49	389.31	790	888	77	0	0	0	52.89
410	185.49	389.31	790	935	35	0	0	0	53.15
411	185.49	389.31	791	795	159	0	0	0	50.36
412	185.49	389.31	791	823	134	0	0	0	51.38
413	185.49	389.31	791	842	117	0	0	0	51.92
414	185.49	389.31	791	870	92	0	0	0	52.52
415	185.49	389.31	791	889	75	0	0	0	52.79
416	185.49	389.31	791	917	50	0	0	0	53.01
417	185.49	389.31	791	936	33	0	0	0	53.04
418	185.49	389.31	791	964	8	0	0	0	52.96
419	185.49	389.31	792	824	132	0	0	0	51.3
420	185.49	389.31	792	871	90	0	0	0	52.43
421	185.49	389.31	792	918	48	0	0	0	52.9
422	185.49	389.31	792	965	6	0	0	0	52.84
423	185.49	389.31	793	806	147	0	0	0	50.56
424	185.49	389.31	793	825	130	0	0	0	51.22
425	185.49	389.31	793	853	105	0	0	0	51.97
426	185.49	389.31	793	872	88	0	0	0	52.34
427	185.49	389.31	793	900	63	0	0	0	52.68
428	185.49	389.31	793	919	46	0	0	0	52.8
429	185.49	389.31	793	947	21	0	0	0	52.81
430	185.49	389.31	793	966	4	0	0	0	52.72
431	185.49	389.31	794	807	145	0	0	0	50.49
432	185.49	389.31	794	854	103	0	0	0	51.89
433	185.49	389.31	794	901	61	0	0	0	52.58
434	185.49	389.31	794	948	19	0	0	0	52.69
435	185.49	389.31	795	808	143	0	0	0	50.42
436	185.49	389.31	795	836	118	0	0	0	51.33
437	185.49	389.31	795	855	101	0	0	0	51.8
438	185.49	389.31	795	883	76	0	0	0	52.28
439	185.49	389.31	795	902	59	0	0	0	52.48
440	185.49	389.31	795	930	34	0	0	0	52.6
441	185.49	389.31	795	949	17	0	0	0	52.27
442	185.49	389.31	796	837	116	0	0	0	51.24
443	185.49	389.31	796	884	74	0	0	0	52.18
444	185.49	389.31	796	931	32	0	0	0	52.48
445	185.49	389.31	797	819	131	0	0	0	50.58
446	185.49	389.31	797	838	114	0	0	0	51.16

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
447	185.49	389.31	797	866	89	0	0	0	51.79
448	185.49	389.31	797	885	72	0	0	0	52.08
449	177.33	351.57	701	721	375	0	0	0	55.34
450	177.33	351.57	701	740	358	0	0	0	55.03
451	177.33	351.57	701	768	333	0	0	0	54.47
452	177.33	351.57	701	787	316	0	0	0	54.03
453	177.33	351.57	701	815	291	0	0	0	53.34
454	178.19	351.57	701	826	279	0	0	0	52.75
455	178.19	351.57	701	845	262	0	0	0	52.23
456	178.19	351.57	701	873	237	0	0	0	51.46
457	178.19	351.57	701	892	220	0	0	0	50.96
458	177.33	351.57	702	722	373	0	0	0	55.27
459	177.33	351.57	702	741	356	0	0	0	54.97
460	177.33	351.57	702	769	331	0	0	0	54.42
461	177.33	351.57	702	788	314	0	0	0	54
462	177.33	351.57	702	816	289	0	0	0	53.33
463	178.19	351.57	702	827	277	0	0	0	52.75
464	178.19	351.57	702	874	235	0	0	0	51.51
465	178.19	352.65	702	901	210	0	0	0	51.1
466	177.33	351.57	703	704	388	0	0	0	55.41
467	177.33	351.57	703	723	371	0	0	0	55.19
468	177.33	351.57	703	751	346	0	0	0	54.74
469	177.33	351.57	703	770	329	0	0	0	54.37
470	177.33	351.57	703	798	304	0	0	0	53.76
471	177.33	351.57	703	817	287	0	0	0	53.32
472	178.19	351.57	703	828	275	0	0	0	52.75
473	179.98	352.65	711	942	159	0	0	0	50.31
474	179.98	352.65	711	961	142	0	0	0	50.01
475	174.05	352.65	711	1065	64	0	0	0	50.83
476	179.98	352.65	713	925	172	0	0	0	50.81
477	179.98	352.65	713	944	155	0	0	0	50.53
478	179.98	352.65	713	972	130	0	0	0	50.14
479	177.33	351.57	714	714	367	0	0	0	54.3
480	177.33	351.57	714	733	350	0	0	0	54.2
481	177.33	351.57	714	761	325	0	0	0	53.99
482	177.33	351.57	714	780	308	0	0	0	53.8
483	177.33	351.57	714	808	283	0	0	0	53.48
484	178.19	351.57	714	866	229	0	0	0	52.38
485	179.98	352.65	714	926	170	0	0	0	50.91
486	179.98	352.65	717	891	198	0	0	0	51.66
487	179.98	352.65	717	910	181	0	0	0	51.43
488	156	273	710.7	1066	0	2.34	0	117	48.52
489	156	273	710.7	533	533	3.12	0	117	43.45
490	156	273	710.7	0	1066	3.9	0	117	45.65
491	195.06	325.1	622.6	1208.5	0	3.25	0	0	39.2
492	208.98	354.2	622.6	1179.4	0	3.25	0	0	37.8
493	167.2	440	656	1022	0	0.9	0	0	52.4
494	167.2	440	656	511	511	1.2	0	0	48.3
495	167.2	440	656	715	307	1.4	0	0	45.7
496	184.8	440	656	511	511	1.2	0	0	42.6
497	167.2	308	656	511	511	1.3	0	132	40.2
498	167.2	220	656	511	511	1.2	0	220	33.6
499	189.84	254	787	543	543	5.71	0	82	33.2
500	190.2	317	787	543	543	5.71	0	0	34.5
501	186.3	222	775	1070	0	7.4	0	192	31.2
502	161.12	320	769	1061	0	8.4	0	104	46.1
503	181.26	360	752	1038	0	9.9	0	117	49.3

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
504	185	370	775	1070	0	7.4	0	0	44.6
505	164.16	273.6	625	485.6	728.4	1.71	0	68.4	33.7
506	164.16	273.6	625	242.8	971.2	1.71	0	68.4	38.7
507	164.16	273.6	625	0	1214	1.71	0	68.4	39.1
508	163.02	334.4	588	952	238	2.09	0	83.6	42.4
509	163.02	334.4	588	714	476	2.09	0	83.6	41.4
510	163.02	334.4	588	476	714	2.09	0	83.6	45.9
511	163.02	334.4	588	238	952	2.09	0	83.6	46
512	163.02	334.4	588	0	1190	2.09	0	83.6	50
513	163.84	409.6	545	925.6	231.4	2.56	0	102.4	55.1
514	163.84	409.6	545	694.2	462.8	2.56	0	102.4	56.7
515	163.84	409.6	545	462.8	684.2	2.56	0	102.4	55.2
516	163.84	409.6	545	231.4	925.6	2.56	0	102.4	53.6
517	163.84	409.6	545	0	1157	2.56	0	102.4	51.4
518	174	300	650	1321	65	3.6	0	0	40.5
519	189	450	596	1210	45	4.8	0	0	55.6
520	160	280	677	1376	10	4.8	0	120	44.7
521	180	500	582	1183	95	6	0	0	61
522	180	393	692	847	283	0	0	0	23.9
523	187.059	393	692	565	565	0	0	0	28.3
524	208.237	393	692	0	1130	0	0	0	27.9
525	183.53	393	692	847	283	0	0	0	24.4
526	194.119	393	692	565	565	0	0	0	30.9
527	180	393	692	0	1130	0	0	0	30
528	187.059	393	692	847	283	0	0	0	28.7
529	180	393	692	565	565	0	0	0	31.3
530	194.119	393	692	0	1130	0	0	0	30.5
531	185	500	601	837	279	0	0	0	38.3
532	191.974	500	601	558	558	0	0	0	34.6
533	212.895	500	601	0	1116	0	0	0	33.4
534	185	349	641	953.6	238.4	0	0	0	20.82
535	185	349	641	715.2	476.8	0	0	0	20.29
536	185	349	641	476.8	715.2	0	0	0	20.71
537	189.86	349	641	238.4	953.6	0	0	0	19.04
538	205.91	349	641	0	1192	0	0	0	17.29
539	139	304	665	1292	0	0	0	0	40.8
540	139	304	665	1033	258	0	0	0	38.6
541	139	304	665	775	517	0	0	0	37.8
542	139	304	665	517	775	0	0	0	34.8
543	139	304	665	258	1033	0	0	0	34
544	145	389	635	986	246	0	0	0	49.8
545	145	389	635	739	493	0	0	0	46.5
546	145	389	635	493	739	0	0	0	43.4
547	145	389	635	246	986	0	0	0	42.3
548	145	389	635	0	1232	0	0	0	40.8
549	148	433	619	1201	0	0	0	0	56.5
550	148	433	619	961	240	0	0	0	53.2
551	148	433	619	721	480	0	0	0	51.9
552	148	433	619	480	721	0	0	0	48.7
553	148	433	619	240	961	0	0	0	46.8
554	148	433	619	0	1201	0	0	0	44.2
555	180	367	686	817	350	4.04	0	0	36.7
556	180	367	686	583	584	4.04	0	0	36.5
557	180	367	686	350	817	4.04	0	0	36.2
558	180	367	686	0	1167	4.04	0	0	33.6
559	180	367	686	817	350	4.04	0	0	36.26
560	180	367	686	583	584	4.04	0	0	34.71

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
561	190	475	607.25	1128	0	0	0	0	39
562	198.8	475	589.75	821	274	0	0	0	37.2
563	207.5	475	589.75	548	548	0	0	0	35.4
564	216.3	475	589.75	274	821	0	0	0	33.6
565	225.1	475	589.75	0	1095	0	0	0	30.4
566	190	422	625.72	1112	0	0	0	0	32.6
567	199	422	608.22	847	282	0	0	0	30.3
568	208.1	422	608.22	565	565	0	0	0	28.1
569	189.6	327	644.95	898	299	0	0	0	23.8
570	199.2	327	644.95	599	599	0	0	0	22.3
571	208.6	327	644.95	299	898	0	0	0	20.8
572	217.7	327	644.95	0	1198	0	0	0	20.6
573	170	283	681.33	1215	0	0	0	0	19.2
574	179.9	283	663.83	925	308	0	0	0	19
575	189.7	283	663.83	616	616	0	0	0	18.9
576	199.6	283	663.83	308	935	0	0	0	19.3
577	208.3	283	663.83	0	1233	0	0	0	19.7
578	164	342	625	1214	0	1.71	0	0	37.2
579	164	342	625	971.2	242.8	1.71	0	0	35.9
580	164	342	625	728.4	485.6	1.71	0	0	37
581	164	342	625	485.6	728.4	1.71	0	0	40.5
582	164	418	588	476	714	2.09	0	0	53.9
583	164	418	588	238	952	2.09	0	0	54.2
584	164	418	588	0	1190	2.09	0	0	43.6
585	164	512	545	1157	0	2.56	0	0	59.5
586	164	512	545	925.6	231.4	2.56	0	0	61.5
587	164	512	545	694.2	462.8	2.56	0	0	62.9
588	164	512	545	462.8	684.2	2.56	0	0	59.3
589	164	512	545	231.4	925.6	2.56	0	0	57.8
590	164	512	545	0	1157	2.56	0	0	56.2
591	164	273.6	625	1214	0	1.71	0	68.4	32.7
592	164	273.6	625	971.2	242.8	1.71	0	68.4	33.7
593	164	273.6	625	728.4	485.6	1.71	0	68.4	33.3
594	164	334.4	588	714	476	2.09	0	83.6	41.4
595	164	334.4	588	476	714	2.09	0	83.6	45.9
596	164	334.4	588	238	952	2.09	0	83.6	42.2
597	164	334.4	588	0	1190	2.09	0	83.6	50
598	164	409.6	545	1157	0	2.56	0	102.4	53.3
599	164	409.6	545	925.6	231.4	2.56	0	102.4	55.1
600	164	409.6	545	694.2	462.8	2.56	0	102.4	56.7
601	164	409.6	545	462.8	684	2.56	0	102.4	55.2
602	164	409.6	545	231.4	925.6	2.56	0	102.4	53.6
603	164	409.6	545	0	1157	2.56	0	102.4	51.4
604	184	340	460	1220	0	0	0	0	27.9
605	184	340	328	1220	0	0	0	0	26.4
606	184	340	196	1220	0	0	0	0	26.7
607	184	340	0	1220	0	0	0	0	25.8
608	189	380	690	0	1140	0	0	0	44.5
609	189	360	700	0	1150	0	0	0	36.8
610	200	500	561	0	1139	0	0	0	33.2
611	241	625	0	0	993	0	0	0	46.8
612	271	625	0	0	959	0	0	0	43.3
613	209	625	0	0	1026	0	0	0	39.1
614	190	380	715	0	874	0	0	0	54.1
615	156	349	888	0	792	0	0	0	41.3
616	157	262	888	0	792	0	0	0	34.5
617	149	335	630	414	720	0	0	0	42.6

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
618	160	358	645	281	813	0	0	0	40.4
619	140	350	732	1109	0	0	0	0	58.6
620	153	340	723	1096	0	0	0	0	56.1
621	225	396	892	558	558	0	0	0	36.1
622	225	396	892	279	836	0	0	0	33.9
623	225	396	892	0	1115	0	0	0	35.4
624	193	645	563	0	921	0	0	0	45.5
625	192	642	561	0	905	0	0	0	57.1
626	192	642	561	0	902	0	0	0	47.1
627	120	400	720	1080	0	0	0	0	70.99
628	180	400	720	108	972	0	0	0	44.2
629	180	400	720	0	1080	0	0	0	41.5
630	200	400	720	1080	0	0	0	0	46
631	180	300	720	756	324	0	0	0	34.92
632	180	300	720	0	1080	0	0	0	27.13
633	190	355	545	445	445	0	0	0	23.08
634	230	430	535	1240	1240	0	0	0	29.3
635	225	267	598	524	506	0	0	0	37.1
636	225	267	598	0	1017	0	0	0	25.2
637	180	400	708	1108	0	0	0	0	66.8
638	180	400	708	886	215	0	0	0	62.4
639	225	360	598	524	506	0	0	0	56.5
640	225	360	598	0	1017	0	0	0	54.5
641	205	410	662	1081	0	0	0	0	54.1
642	180	375	665	520	504	0	0	0	63.4
643	180	375	665	0	1009	0	0	0	61.1
644	160	400	729	1140	0	0	0	0	72.3
645	160	400	729	912	221	0	0	0	69.6
646	185	369	628	305	914	0	0	0	27
647	185	369	628	0	1218	0	0	0	25.7
648	229	353	647	527	513	0	0	0	44.7
649	247	353	647	524	496	0	0	0	39.7
650	207	353	649	531	531	0	0	0	38.1
651	241	353	625	0	993	0	0	0	46.8
652	271	353	625	0	959	0	0	0	43.3
653	189	420	523	0	1211	0	0	0	21
654	190	422	616	1113	0	0	0	0	32.5
655	199	422	607	850	283	0	0	0	30.1
656	167	235	1010	235	650	0	0	0	20.15
657	158	220	1020	920	0	0	0	0	18.25
658	158	220	1020	230	650	0	0	0	17.43
659	170	240	990	890	0	0	0	0	24.27
660	214.75	488.36	524	813	268	0	0	0	34.18
661	214.57	488.36	524	837	247	0	0	0	33.78
662	214.57	488.36	524	856	230	0	0	0	33.5
663	216.35	488.36	524	889	196	0	0	0	32.91
664	216.35	488.36	524	898	188	0	0	0	32.84
665	216.35	488.36	524	917	171	0	0	0	32.73
666	216.35	488.36	524	936	154	0	0	0	32.67
667	216.35	488.36	524	945	146	0	0	0	32.66
668	216.35	488.36	524	964	129	0	0	0	32.67
669	216.35	488.86	524	987	108	0	0	0	32.8
670	216.35	489.35	524	1000	96	0	0	0	32.93
671	216.35	489.35	524	1019	79	0	0	0	33.04
672	216.35	489.35	524	1047	54	0	0	0	33.26
673	214.65	489.35	524	1082	27	0	0	0	33.77
674	216.35	488.36	525	918	169	0	0	0	32.63

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
675	216.35	488.36	525	946	144	0	0	0	32.57
676	216.35	488.36	525	965	127	0	0	0	32.58
677	216.35	489.35	525	1001	94	0	0	0	32.86
678	216.35	489.35	525	1029	69	0	0	0	33.04
679	216.35	489.35	525	1048	52	0	0	0	33.2
680	214.65	489.35	525	1083	25	0	0	0	33.72
681	183.21	369.84	525	1171	126	0	0	0	31.46
682	183.21	369.84	525	1190	109	0	0	0	31.19
683	214.75	488.36	526	787	289	0	0	0	34.55
684	195.83	374.66	646	816	285	0	0	0	42.8
685	196.68	374.66	646	827	273	0	0	0	41.26
686	196.68	374.66	646	837	264	0	0	0	40.44
687	195.83	374.66	647	798	300	0	0	0	44.45
688	195.83	374.66	647	808	291	0	0	0	43.57
689	195.83	374.66	647	817	283	0	0	0	42.79
690	196.68	374.66	647	828	271	0	0	0	41.24
691	195.83	374.66	648	799	298	0	0	0	44.43
692	195.83	374.66	648	809	289	0	0	0	43.55
693	195.83	374.66	648	818	281	0	0	0	42.77
694	196.68	374.66	648	829	269	0	0	0	41.23
695	196.68	374.66	648	838	261	0	0	0	40.51
696	195.83	374.66	649	800	296	0	0	0	44.41
697	195.83	374.66	649	810	287	0	0	0	43.53
698	195.83	374.66	649	819	279	0	0	0	42.76
699	196.68	374.66	649	830	267	0	0	0	41.22
700	196.68	374.66	649	839	259	0	0	0	40.5
701	178.19	337.22	650	962	225	0	0	0	40.28
702	178.19	343.87	650	975	208	0	0	0	40.93
703	214.75	484.5	500	591	509	0	0	0	40.55
704	214.75	484.5	500	600	501	0	0	0	40.41
705	214.75	484.5	500	619	484	0	0	0	40.1
706	208.81	428.6	501	503	647	0	0	0	41.85
707	208.81	428.6	501	513	638	0	0	0	41.84
708	208.81	428.6	501	522	630	0	0	0	41.81
709	211.49	484.75	501	526	574	0	0	0	41.43
710	208.81	428.6	501	541	613	0	0	0	41.72
711	209.4	484.75	501	542	565	0	0	0	41.4
712	211.49	428.6	501	548	600	0	0	0	41.65
713	208.81	428.6	501	550	605	0	0	0	41.66
714	209.4	484.75	501	552	556	0	0	0	41.32
715	211.49	428.6	501	557	592	0	0	0	41.57
716	209.4	484.75	501	561	548	0	0	0	41.24
717	211.49	428.6	501	567	583	0	0	0	41.46
718	209.4	484.75	501	570	540	0	0	0	41.15
719	215.33	484.75	501	579	517	0	0	0	40.68
720	214.75	484.5	501	592	507	0	0	0	40.52
721	214.75	484.5	501	601	499	0	0	0	40.38
722	214.75	484.5	501	610	491	0	0	0	40.23
723	214.75	484.5	501	620	482	0	0	0	40.06
724	208.81	428.6	502	504	645	0	0	0	41.88
725	208.81	428.6	502	514	636	0	0	0	41.86
726	208.81	428.6	502	523	628	0	0	0	41.84
727	211.49	484.75	502	527	572	0	0	0	41.42
728	208.81	428.6	502	532	620	0	0	0	41.8
729	208.81	428.6	502	542	611	0	0	0	41.74
730	209.4	484.75	502	543	563	0	0	0	41.4
731	211.49	428.6	502	549	598	0	0	0	41.66

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
732	211.49	428.6	502	558	590	0	0	0	41.58
733	209.4	484.75	502	562	546	0	0	0	41.23
734	211.49	428.6	502	568	581	0	0	0	41.47
735	209.4	484.75	502	571	538	0	0	0	41.13
736	215.33	484.75	502	580	515	0	0	0	40.65
737	214.75	484.5	502	602	497	0	0	0	40.34
738	214.75	484.5	502	611	489	0	0	0	40.19
739	214.75	484.5	502	621	480	0	0	0	40.01
740	208.81	428.6	503	505	643	0	0	0	41.91
741	208.81	428.6	503	524	626	0	0	0	41.86
742	211.49	484.75	503	528	570	0	0	0	41.42
743	208.81	428.6	503	533	618	0	0	0	41.82
744	208.81	428.6	503	543	609	0	0	0	41.76
745	209.4	484.75	503	544	561	0	0	0	41.39
746	211.49	428.6	503	550	596	0	0	0	41.67
747	209.4	484.75	503	553	553	0	0	0	41.31
748	211.49	428.6	503	559	588	0	0	0	41.58
749	209.4	484.75	503	563	544	0	0	0	41.22
750	209.4	484.75	503	572	536	0	0	0	41.12
751	214.75	484.5	503	584	512	0	0	0	40.61
752	214.75	484.5	503	593	504	0	0	0	40.47
753	214.75	484.5	503	603	495	0	0	0	40.3
754	214.75	484.5	503	612	487	0	0	0	40.14
755	216.9	363.1	600	1045	87	0	0	0	40.15
756	216.9	363.1	600	1054	79	0	0	0	40.45
757	215.2	359.75	600	1082	61	0	0	0	40.06
758	216.9	363.1	601	1046	85	0	0	0	40.33
759	216.9	363.1	601	1055	77	0	0	0	40.63
760	185.49	389.31	797	913	47	0	0	0	52.32
761	185.49	389.31	797	932	30	0	0	0	52.36
762	185.49	389.31	797	960	5	0	0	0	52.29
763	185.49	389.31	798	820	129	0	0	0	50.5
764	185.49	389.31	798	867	87	0	0	0	51.7
765	185.49	389.31	798	914	45	0	0	0	52.21
766	185.49	389.31	798	961	3	0	0	0	52.17
767	185.49	389.31	799	821	127	0	0	0	50.42
768	185.49	389.31	799	849	102	0	0	0	51.21
769	185.49	389.31	799	868	85	0	0	0	51.6
770	185.49	389.31	799	896	60	0	0	0	51.97
771	185.49	389.31	799	915	43	0	0	0	52.09
772	185.49	389.31	799	943	18	0	0	0	52.12
773	185.49	389.31	799	962	1	0	0	0	52.04
774	185.49	389.31	800	850	100	0	0	0	51.12
775	185.49	389.31	800	897	58	0	0	0	51.86
776	185.49	389.31	800	944	16	0	0	0	51.99
777	177.33	351.57	712	731	354	0	0	0	54.4
778	177.33	351.57	712	750	337	0	0	0	54.23
779	177.33	351.57	712	778	312	0	0	0	53.91
780	177.33	351.57	712	797	295	0	0	0	53.66
781	178.19	351.57	712	836	258	0	0	0	52.77
782	178.19	351.57	712	883	216	0	0	0	52
783	179.98	352.65	712	896	199	0	0	0	51.19
784	179.98	352.65	712	943	157	0	0	0	50.42
785	177.33	351.57	713	713	369	0	0	0	54.41
786	177.33	351.57	713	732	352	0	0	0	54.3
787	177.33	351.57	713	760	327	0	0	0	54.06
788	177.33	351.57	713	779	310	0	0	0	53.85

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Compressive Strength [MPa]
789	177.33	351.57	713	807	285	0	0	0	53.51
790	178.19	351.57	713	837	256	0	0	0	52.77
791	178.19	351.57	713	865	231	0	0	0	52.35
792	179.98	352.65	713	897	197	0	0	0	51.26
793	180	450	752	519	519	9.9	0	0	43.8
794	184.8	336	785	542	542	6.38	0	0	35.1
795	180	450	752	1038	0	9.9	0	0	51.9
796	185.12	269	785	542	542	6.38	0	87	34.4
797	184.73	202	785	542	542	6.38	0	175	28.5
798	185.38	259	775	535	535	7.4	0	144	31.9
799	179.2	240	769	1061	0	8.4	0	208	39
800	184.79	333	775	1070	0	7.4	0	48	41.2
801	189.93	190	787	1086	0	5.71	0	165	28.1
802	181.26	360	752	519	519	9.9	0	117	40.1
803	181.44	270	752	519	519	9.9	0	234	36.8
804	180	400	769	1061	0	8.4	0	0	49.5
805	184.24	296	775	535	535	7.4	0	96	36
806	164.16	273.6	625	1214	0	1.71	0	68.4	32.7
807	164.16	273.6	625	971.2	242.8	1.71	0	68.4	33.7
808	188.487	500	601	837	279	0	0	0	33.6
809	198.948	500	601	558	558	0	0	0	32.9
810	185	500	601	0	1116	0	0	0	35.3
811	191.974	500	601	837	279	0	0	0	38.4
812	185	500	601	558	558	0	0	0	37.9
813	198.948	500	601	0	1116	0	0	0	37.2
814	185	349	641	1192	0	0	0	0	20.1
815	139	304	665	0	1292	0	0	0	32.4
816	142	346	650	1262	0	0	0	0	46.2
817	142	346	650	1010	252	0	0	0	44.8
818	142	346	650	757	505	0	0	0	43
819	142	346	650	505	757	0	0	0	42
820	142	346	650	252	1010	0	0	0	40.2
821	142	346	650	0	1262	0	0	0	39.3
822	145	389	635	1232	0	0	0	0	51.2
823	180	367	686	350	817	4.04	0	0	32.09
824	180	367	686	0	1167	4.04	0	0	30.25
825	217.1	422	608.22	282	847	0	0	0	26.6
826	226.2	422	608.22	0	1130	0	0	0	25.3
827	180	360	651	1159	0	0	0	0	26.4
828	189.4	360	633.5	882	294	0	0	0	24.1
829	198.8	360	633.5	588	588	0	0	0	24.2
830	208.2	360	633.5	294	882	0	0	0	21.6
831	217	360	633.5	0	1177	0	0	0	18.9
832	180	327	662.45	1180	0	0	0	0	24.7
833	164	342	625	242.8	971.2	1.71	0	0	40.7
834	164	342	625	0	1214	1.71	0	0	42.3
835	164	418	588	1190	0	2.09	0	0	47.7
836	164	418	588	952	238	2.09	0	0	52.5
837	164	418	588	714	476	2.09	0	0	49.8
838	164	273.6	625	485.6	728.4	1.71	0	68.4	33.7
839	164	273.6	625	242.8	971.2	1.71	0	68.4	38.7
840	164	273.6	625	0	1214	1.71	0	68.4	39.1
841	164	334.4	588	1190	0	2.09	0	83.6	44.1
842	164	334.4	588	952	238	2.09	0	83.6	42.2
843	271	667	1020	1376	1292	9.9	0	234	80.4
844	116	218	175	0	0	0	0	0	17.29

Appendix B

Recycled aggregate elastic modulus prediction concrete mix ratio data set [34–117].

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
1	185	349	641	1192	0	0	0	0	32.7
2	185	349	641	953.6	238.4	0	0	0	22.8
3	185	349	641	476.8	715.2	0	0	0	28.5
4	189.86	349	641	238.4	953.6	0	0	0	24.5
5	205.91	349	641	0	1192	0	0	0	26.3
6	180	367	686	817	350	4.04	0	0	39.9
7	180	367	686	583	584	4.04	0	0	38.2
8	180	367	686	350	817	4.04	0	0	32.2
9	180	367	686	0	1167	4.04	0	0	30.8
10	180	367	686	817	350	4.04	0	0	33.7
11	180	367	686	583	584	4.04	0	0	31.8
12	180	367	686	350	817	4.04	0	0	30.5
13	180	367	686	0	1167	4.04	0	0	28.4
14	200	454	595	576	576	0	0	0	34.6
15	200	454	595	0	1152	0	0	0	33.1
16	200	318	595	576	576	0	0	136	37.3
17	200	318	595	0	1152	0	0	136	34.4
18	200	449	595	576	576	4.54	0	0	39.2
19	200	449	595	0	1152	4.54	0	0	37.3
20	200	315	595	576	576	4.54	0	136	39.8
21	200	315	595	0	1152	4.54	0	136	38.8
22	200	500	545	578	578	0	0	0	39.8
23	200	500	545	0	1156	0	0	0	38.5
24	200	350	545	578	578	0	0	150	41
25	200	350	545	0	1156	0	0	150	39.8
26	200	495	545	578	578	5	0	0	39.5
27	200	495	545	0	1156	5	0	0	38.5
28	200	347	545	1156	0	5	0	148	44.9
29	200	347	545	578	578	5	0	148	42
30	200	347	545	0	1156	5	0	148	39.3
31	185	349	641	1192	0	0	0	0	29.2
32	185	349	641	953.6	238.4	0	0	0	28.6
33	185	349	641	715.2	476.8	0	0	0	27.2
34	185	349	641	476.8	715.2	0	0	0	26.6
35	185	379	588	998.2	249.8	0	0	0	38.3
36	185	379	588	748.4	499.6	0	0	0	40.1
37	185	379	588	499.6	748.4	0	0	0	38.6
38	185	379	588	249.8	998.2	0	0	0	38.2
39	109	191	908	1096	0	4.5	0	56	25.91
40	113.29	191	908	986	110	4.5	0	56	24.15
41	117.54	191	908	877	219	4.5	0	56	23.75
42	121.83	191	908	768	329	4.5	0	56	21.27
43	126.08	191	908	658	438	4.5	0	56	20.65
44	130.37	191	908	548	548	4.5	0	56	10
45	134.66	191	908	438	658	4.5	0	56	18.51
46	104.2	213	897.8	1077	0	5.1	0	63	28.85
47	108.412	213	897.8	969	108	5.1	0	63	27.57
48	112.585	213	897.8	862	215	5.1	0	63	25.34
49	116.797	213	897.8	754	323	5.1	0	63	23.73
50	121.009	213	897.8	646	431	5.1	0	63	22.59
51	115	268	832	1051	0	6.4	0	79	31.69
52	119.095	268	832	946	105	6.4	0	79	30.41
53	123.19	268	832	841	210	6.4	0	79	29.22

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
54	128.207	275	827	731	313	6.5	0	82	27.44
55	132.302	275	827	626	418	6.5	0	82	26.79
56	136.358	275	827	522	522	6.5	0	82	25.47
57	140.414	275	827	418	626	6.5	0	82	24.46
58	126	291	789	1049	0	6.9	0	86	33.11
59	130.095	291	789	944	105	6.9	0	86	32.28
60	134.19	291	789	839	210	6.9	0	86	30.36
61	138.207	299	784	729	313	7.1	0	89	29.61
62	142.263	299	784	625	417	7.1	0	89	28.81
63	146.319	299	784	521	521	7.1	0	89	27.72
64	150.375	299	784	417	625	7.1	0	89	24.76
65	165	310	680	1010	0	4.6	0	65	33.2
66	165	310	680	758	252	4.6	0	65	27.8
67	165	310	680	0	1010	4.6	0	65	21.1
68	215	500	465	1199	0	0	0	0	30.1
69	219	500	465	839	360	0	0	0	29.6
70	222	500	465	600	600	0	0	0	28.3
71	223	500	465	839	360	0	0	0	27.6
72	230	500	465	600	600	0	0	0	23.6
73	237	500	465	360	839	0	0	0	21.1
74	246	500	465	0	1199	0	0	0	20.3
75	220	500	465	839	360	0	0	0	22.4
76	223	500	465	600	600	0	0	0	19.3
77	226	500	465	360	839	0	0	0	17
78	231	500	465	0	1199	0	0	0	15.6
79	175.6	390	572	1268	0	0.95	0	0	32.4
80	175.6	390	572	918	306	0.95	0	0	26.5
81	175.6	390	572	0	1112	0.95	0	0	20.8
82	185	349	641	1192	0	0	0	0	32.7
83	185	349	641	953.6	238.4	0	0	0	22.8
84	185	349	641	715.2	476.8	0	0	0	26.7
85	189.86	349	641	238.4	953.6	0	0	0	24.5
86	205.91	349	641	0	1192	0	0	0	26.3
87	180	400	708	1108	0	0	0	0	38.7
88	180	300	688	1108	0	0	0	100	36.3
89	180	300	688	886	215	0	0	100	29.3
90	180	300	688	554	538	0	0	100	27.1
91	180	300	688	0	1075	0	0	100	23.2
92	186	373	737	0	1020	0	0	0	26.6
93	186	280	737	1098	0	0	0	93	30.55
94	186	242	737	1098	0	0	0	131	28.5
95	186	280	737	0	1020	0	0	93	25.47
96	186	242	737	0	1020	0	0	131	24.32
97	175.6	390	572	1268	0	0.95	0	0	32.4
98	175.6	390	572	918	306	0.95	0	0	26.5
99	175.6	390	572	588	588	0.95	0	0	23.2
100	188	250.7	750	611.5	611.5	0	0	0	32.9
101	190.6	254.7	750	306	917	0	0	0	29.4
102	193.5	258	750	0	1223	0	0	0	28.4
103	187	334	601	1278	0	0	0	0	39.1
104	191.6	342.2	601	895	383	0	0	0	36.5
105	194.7	347.8	601	639	639	0	0	0	33.7
106	198.7	354.9	601	320	958	0	0	0	31.1
107	203.1	362.8	601	0	1278	0	0	0	28.5
108	205	477	498	1220	0	0	0	0	39.3
109	210.2	489.1	498	854	366	0	0	0	36.3
110	213.5	496.7	498	610	610	0	0	0	33.3

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
111	218.1	507.5	498	305	915	0	0	0	31.4
112	175	356	658	855	317	0	0	0	30.2
113	175	285	580	822	305	0	0	71	27.3
114	175	214	548	840	311	0	0	142	24.7
115	181	303	648	838	309	0	0	65	26.3
116	175	356	552	855	317	0	0	107	36
117	225	325	880	925	0	0	0	0	27
118	225	325	765	890	0	0	0	0	24
119	225	325	725	840	0	0	0	0	18.5
120	158	450	685	873	0	0	0	0	31.3
121	158	450	673	707	0	0	0	0	21.7
122	158	450	673	707	0	0	0	0	24.2
123	158	450	657	493	0	0	0	0	16.8
124	158	450	657	493	0	0	0	0	15.5
125	198	395	664	1083	0	0	0	0	29.6
126	198	395	653	906	0	0	0	0	21.2
127	198	395	643	735	0	0	0	0	18.4
128	198	395	643	735	0	0	0	0	20
129	198	395	622	508	0	0	0	0	9.7
130	198	395	622	508	0	0	0	0	12
131	209	380	670	570	570	0	0	0	33
132	209	380	670	0	1140	0	0	0	26
133	209	380	670	570	570	0	0	0	35
134	213	350	720	540	480	0	0	0	29.1
135	153	437	730	1095	0	0	38	0	41.3
136	193	437	730	0	910	0	38	0	31.9
137	180	437	730	0	973	0	38	0	41.5
138	227.5	325	955	1010	0	0	0	0	28
139	227.5	325	880	925	0	0	0	0	27
140	227.5	325	765	890	0	0	0	0	24
141	227.5	325	725	840	0	0	0	0	18.5
142	157.5	450	685	873	0	0	0	0	31.3
143	157.5	450	673	707	0	0	0	0	21.7
144	157.5	450	673	707	0	0	0	0	24.2
145	157.5	450	657	493	0	0	0	0	16.8
146	157.5	450	657	493	0	0	0	0	15.5
147	197.5	395	664	1083	0	0	0	0	29.6
148	197.5	395	653	906	0	0	0	0	21.2
149	197.5	395	643	735	0	0	0	0	18.4
150	197.5	395	643	735	0	0	0	0	20
151	197.5	395	622	508	0	0	0	0	9.7
152	225	410	642	1048	0	0	0	0	30.1
153	225	410	642	524	506	0	0	0	26.3
154	225	307.5	611	524	506	0	0	102.5	27.7
155	225	307.5	611	0	1017	0	0	102.5	23.9
156	225	266.5	598	1048	0	0	0	143.5	28.5
157	225	266.5	598	524	506	0	0	143.5	24.8
158	225	266.5	598	0	1017	0	0	143.5	21.6
159	225	184.5	530	1048	0	0	0	225.5	26.4
160	225	184.5	530	524	506	0	0	225.5	22.1
161	225	184.5	530	0	1017	0	0	225.5	20.4
162	192.75	388.95	845.86	0	770	2.029	0	118.3	23.4
163	198.96	401.47	836.46	192.13	576.37	2.094	0	122.11	20.4
164	198.96	401.47	836.46	768.5	0	2.094	0	122.11	18.5
165	214	523	531	902	225	0	0	0	14.03
166	214	523	531	791	338	0	0	0	13.16
167	214	523	531	676	451	0	0	0	13.05

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
168	214	523	531	565	565	0	0	0	13.69
169	214	523	531	451	676	0	0	0	14.12
170	214	523	531	338	791	0	0	0	13.88
171	214	523	531	225	902	0	0	0	14.05
172	214	523	531	112	1017	0	0	0	13.51
173	214	523	531	0	1128	0	0	0	13.22
174	195.5	325.1	622.6	1208.5	0	3.25	0	0	28
175	201.5	354.2	622.6	604.3	604.3	3.25	0	0	24.3
176	207.6	354.2	622.6	0	1208.5	3.25	0	0	19.52
177	195.5	330.1	607.6	1179.4	0	3.57	0	53.5	28.91
178	201.4	330.1	607.6	589.7	589.7	3.57	0	53.5	23.46
179	222	366	581	563.9	563.9	4.2	0	126.1	27.99
180	227.7	366	581	0	1127.9	4.2	0	126.1	23.5
181	204.8	435.7	564.3	780.6	334.6	0	0	0	3.84
182	204.8	435.7	564.3	334.6	780.6	0	0	0	3.89
183	204.8	435.7	564.3	0	1115.2	0	0	0	3.67
184	208.42	404	614	1228	0	0	0	0	44.4
185	208.85	404	614	1105	123	0	0	0	39.3
186	209.26	404	614	982	245	0	0	0	39.4
187	209.71	404	614	860	368	0	0	0	39.6
188	210.14	404	614	737	491	0	0	0	36.5
189	210.57	404	614	614	614	0	0	0	41
190	211	404	614	491	737	0	0	0	35.8
191	211.43	404	614	368	860	0	0	0	36.5
192	211.84	404	614	245	982	0	0	0	38.2
193	195	400	582	1200	0	0	0	0	29.4
194	195	400	582	0	1060	0	0	0	30.6
195	195	400	582	0	960	0	0	0	26.1
196	195	360	582	0	960	0	0	0	27.3
197	195	280	582	0	960	0	0	0	24.9
198	202	367	697	0	972	0	0	61	23.126
199	207	367	713	972	0	0	0	61	31.372
200	180	546	677	0	918	0	0	77	29.014
201	180	546	677	918	0	0	0	77	36.888
202	202	308	697	0	972	0	0	120	22.581
203	202	308	697	972	0	0	0	120	28.959
204	202	367	697	0	972	0	0	61	21.719
205	190	380	750.12	562.07	473.81	0	0	0	27.4833
206	190	380	752.514	894.247	188.639	0	0	0	29.415
207	190	380	745.712	0	949.088	0	0	0	24.8
208	190	380	749.36	1124.04	0	0	0	0	31.58
209	157.5	450	677.16	0	1104.84	0	0	0	29.26
210	157.5	450	682.29	0	1113.21	0	0	0	28.85
211	157.5	450	684	0	1116	0	0	0	28.8
212	174	300	665.76	560.5	525.74	0	0	0	22.27
213	190	380	761.292	555.406	495.902	0	0	0	27.5
214	174	300	653.22	0	1065.78	0	0	0	22.1
215	178.5	350	657.86	578.216	541.924	0	0	0	25.57
216	178.5	350	661.01	0	1078.49	0	0	0	24.64
217	190	380	750.12	0	1035.88	0	0	0	26.91
218	190	380	745.712	0	949.088	0	0	0	25.34
219	190	380	750.12	562.068	473.812	0	0	0	27.307
220	190	380	752.514	894.247	188.639	0	0	0	29.32
221	157.5	450	680.58	0	1110.42	0	0	0	29.05
222	191.25	375	815.063	996.188	0	0	0	0	31.5
223	205	410	835.744	0	869.856	0	0	0	26.167
224	189	315	895.104	969.696	0	0	0	0	36.5

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
225	204	340	962.064	0	819.536	0	0	0	24
226	189.8	260	1038.96	885.04	0	0	0	0	28.5
227	206.25	275	1073.435	0	777.315	0	0	0	22
228	220	367	725	1088	0	0	0	0	31.967
229	200	500	578	1122	0	0	0	0	38.067
230	220	367	725	870.4	217.6	0	0	0	29.4
231	220	367	725	652.8	435.2	0	0	0	28.967
232	220	367	725	435.2	652.8	0	0	0	29.4
233	220	367	725	217.6	870.4	0	0	0	28.367
234	220	440	644	438.4	657.6	0	0	0	31.167
235	220	440	644	657.6	438.4	0	0	0	30.967
236	220	440	644	219.2	348.16	0	0	0	31.067
237	200	500	578	673.2	448.8	0	0	0	34.633
238	200	500	578	448.8	673.2	0	0	0	34.067
239	200	500	578	224.4	897.6	0	0	0	33.6
240	200	500	578	0	1122	0	0	0	33.467
241	220	367	725	870.4	217.6	0	0	0	28.8
242	220	367	725	652.8	435.2	0	0	0	29
243	220	367	725	435.2	652.8	0	0	0	27.733
244	220	367	725	217.6	870.4	0	0	0	28.4
245	220	440	644	438.4	657.6	0	0	0	31.1
246	220	440	644	657.6	438.4	0	0	0	31.133
247	220	440	644	219.2	348.16	0	0	0	30.633
248	220	440	644	0	1096	0	0	0	29.333
249	200	500	578	897.6	224.4	0	0	0	34.833
250	200	500	578	673.2	448.8	0	0	0	34.8
251	200	500	578	448.8	673.2	0	0	0	34.2
252	200	500	578	224.4	897.6	0	0	0	33.667
253	220	367	725	652.8	435.2	0	0	0	27.4
254	220	367	725	435.2	652.8	0	0	0	24.767
255	220	367	725	217.6	870.4	0	0	0	23.7
256	220	367	725	0	1088	0	0	0	23.333
257	220	440	644	876.8	219.2	0	0	0	31.4
258	220	440	644	438.4	657.6	0	0	0	29.9
259	220	440	644	657.6	438.4	0	0	0	27.167
260	220	440	644	219.2	348.16	0	0	0	26.467
261	200	500	578	673.2	448.8	0	0	0	33.3
262	200	500	578	448.8	673.2	0	0	0	30.433
263	200	500	578	224.4	897.6	0	0	0	29.067
264	200	500	578	0	1122	0	0	0	27.233
265	220	367	725	870.4	217.6	0	0	0	27.233
266	220	367	725	652.8	435.2	0	0	0	27.133
267	220	367	725	435.2	652.8	0	0	0	23.967
268	220	367	725	217.6	870.4	0	0	0	23.467
269	220	440	644	438.4	657.6	0	0	0	29.233
270	220	440	644	657.6	438.4	0	0	0	25.8
271	220	440	644	219.2	348.16	0	0	0	25.933
272	220	440	644	0	1096	0	0	0	23.133
273	200	500	578	897.6	224.4	0	0	0	31.967
274	200	500	578	673.2	448.8	0	0	0	31.5
275	200	500	578	448.8	673.2	0	0	0	28.433
276	200	500	578	224.4	897.6	0	0	0	27.4
277	185	349	641	715.2	476.8	0	0	0	26.7
278	180	367	686	350	817	4.04	0	0	32.2
279	200	454	595	1152	0	0	0	0	35.5
280	200	318	595	1152	0	0	0	136	39.2
281	200	449	595	1152	0	4.54	0	0	39.9

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
282	200	315	595	1152	0	4.54	0	136	40.4
283	200	500	545	1156	0	0	0	0	41.2
284	200	350	545	1156	0	0	0	150	43.9
285	200	495	545	1156	0	5	0	0	42
286	185	349	641	238.4	953.6	0	0	0	25.2
287	185	379	588	1249	0	0	0	0	43.2
288	125.221	213	897.8	538	539	5.1	0	63	21.8
289	129.394	213	897.8	431	646	5.1	0	63	19.74
290	94	238	873	1076	0	5.6	0	70	30.68
291	98.212	238	873	968	108	5.6	0	70	28.93
292	102.385	238	873	861	215	5.6	0	70	27.74
293	107.48	249	865	746	320	5.9	0	74	26.3
294	111.614	249	865	640	426	5.9	0	74	25.31
295	115.787	249	865	533	533	5.9	0	74	24.11
296	119.96	249	865	426	640	5.9	0	74	22.25
297	165	310	680	505	505	4.6	0	65	24.3
298	225	500	465	360	839	0	0	0	26.4
299	229	500	465	0	1199	0	0	0	23.8
300	175.6	390	572	588	588	0.95	0	0	23.2
301	185	349	641	476.8	715.2	0	0	0	28.5
302	180	260	688	1108	0	0	0	140	31.3
303	186	373	737	1098	0	0	0	0	30.45
304	175.6	390	572	0	1112	0.95	0	0	20.8
305	163	283	631	0	978	3.77	0	31.39	23.375
306	158	320	658	0	929	4.27	0	35.58	24.194
307	163	350	569	0	967	4.66	0	38.87	27.095
308	183	244	750	1223	0	0	0	0	38.6
309	185	246.7	750	856	367	0	0	0	36.3
310	223.2	519.3	498	0	1220	0	0	0	28.8
311	175	356	658	1221	0	0	0	0	31.5
312	175	356	498	855	317	0	0	178	21.6
313	225	325	955	1010	0	0	0	0	28
314	225	325	545	825	0	0	0	0	13.5
315	158	450	697	1046	0	0	0	0	35.8
316	209	380	670	0	1140	0	0	0	28
317	199	350	720	1080	0	0	0	0	30
318	216	350	720	540	465	0	0	0	26.7
319	227.5	325	545	825	0	0	0	0	13.5
320	157.5	450	697	1046	0	0	0	0	35.8
321	197.5	395	622	508	0	0	0	0	12
322	225	410	642	0	1017	0	0	0	22.5
323	225	307.5	611	1048	0	0	0	102.5	29.1
324	198.96	401.47	836.46	384.25	384.25	2.094	0	122.11	18.8
325	214	523	531	1128	0	0	0	0	14.93
326	214	523	531	1017	112	0	0	0	13.77
327	207.3	330.1	607.6	0	1179.4	3.57	0	53.5	20.45
328	216.3	366	581	1127.9	0	4.2	0	126.1	30
329	204.8	435.7	564.3	1115.2	0	0	0	0	3.72
330	212.29	404	614	123	1105	0	0	0	34.2
331	212.72	404	614	0	1228	0	0	0	36.3
332	195	320	582	0	960	0	0	0	26.6
333	202	367	697	972	0	0	0	61	27.759
334	190	380	753.274	0	998.526	0	0	0	26.78
335	157.5	450	673.74	0	1099.26	0	0	0	28.18
336	187	425	653.055	0	1021.445	0	0	0	28.73
337	164.9	485	652.5675	0	1020.683	0	0	0	30.22
338	190	380	745.712	0	949.088	0	0	0	25.25

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
339	157.5	450	673.92	1198.08	0	0	0	0	32.3
340	220	440	644	1096	0	0	0	0	35.1
341	220	367	725	0	1088	0	0	0	28.033
342	220	440	644	876.8	219.2	0	0	0	32.333
343	220	440	644	0	1096	0	0	0	30.6
344	200	500	578	897.6	224.4	0	0	0	35.533
345	220	367	725	0	1088	0	0	0	25.633
346	220	440	644	876.8	219.2	0	0	0	31.3
347	200	500	578	0	1122	0	0	0	31.9
348	220	367	725	870.4	217.6	0	0	0	28.567
349	220	440	644	0	1096	0	0	0	24.5
350	200	500	578	897.6	224.4	0	0	0	34.467
351	220	367	725	0	1088	0	0	0	20.567
352	220	440	644	876.8	219.2	0	0	0	28.9
353	200	500	578	0	1122	0	0	0	24.533
354	185	349	641	715.2	476.8	0	0	0	26.7
355	180	367	686	350	817	4.04	0	0	32.2
356	200	454	595	1152	0	0	0	0	35.5
357	200	318	595	1152	0	0	0	136	39.2
358	200	449	595	1152	0	4.54	0	0	39.9
359	200	315	595	1152	0	4.54	0	136	40.4
360	200	500	545	1156	0	0	0	0	41.2
361	200	350	545	1156	0	0	0	150	43.9
362	200	495	545	1156	0	5	0	0	42
363	185	349	641	238.4	953.6	0	0	0	25.2
364	185	379	588	1249	0	0	0	0	43.2
365	125.221	213	897.8	538	539	5.1	0	63	21.8
366	129.394	213	897.8	431	646	5.1	0	63	19.74
367	94	238	873	1076	0	5.6	0	70	30.68
368	98.212	238	873	968	108	5.6	0	70	28.93
369	102.385	238	873	861	215	5.6	0	70	27.74
370	107.48	249	865	746	320	5.9	0	74	26.3
371	111.614	249	865	640	426	5.9	0	74	25.31
372	115.787	249	865	533	533	5.9	0	74	24.11
373	119.96	249	865	426	640	5.9	0	74	22.25
374	165	310	680	505	505	4.6	0	65	24.3
375	225	500	465	360	839	0	0	0	26.4
376	229	500	465	0	1199	0	0	0	23.8
377	175.6	390	572	588	588	0.95	0	0	23.2
378	185	349	641	476.8	715.2	0	0	0	28.5
379	180	260	688	1108	0	0	0	140	31.3
380	186	373	737	1098	0	0	0	0	30.45
381	175.6	390	572	0	1112	0.95	0	0	20.8
382	163	283	631	0	978	3.77	0	31.39	23.375
383	158	320	658	0	929	4.27	0	35.58	24.194
384	163	350	569	0	967	4.66	0	38.87	27.095
385	183	244	750	1223	0	0	0	0	38.6
386	185	246.7	750	856	367	0	0	0	36.3
387	223.2	519.3	498	0	1220	0	0	0	28.8
388	175	356	658	1221	0	0	0	0	31.5
389	175	356	498	855	317	0	0	178	21.6
390	225	325	955	1010	0	0	0	0	28
391	225	325	545	825	0	0	0	0	13.5
392	158	450	697	1046	0	0	0	0	35.8
393	209	380	670	0	1140	0	0	0	28
394	199	350	720	1080	0	0	0	0	30
395	216	350	720	540	465	0	0	0	26.7

Number	Water [kg]	Cement [kg]	Natural Fine Aggregate [kg]	Natural Coarse Aggregate [kg]	Recycled Coarse Aggregate [kg]	Water Reducer [kg]	Silicon Ash [kg]	Fly Ash [kg]	Elastic Modulus [GPa]
396	227.5	325	545	825	0	0	0	0	13.5
397	157.5	450	697	1046	0	0	0	0	35.8
398	197.5	395	622	508	0	0	0	0	12
399	225	410	642	0	1017	0	0	0	22.5
400	225	307.5	611	1048	0	0	0	102.5	29.1
401	198.96	401.47	836.46	384.25	384.25	2.094	0	122.11	18.8
402	214	523	531	1128	0	0	0	0	14.93
403	214	523	531	1017	112	0	0	0	13.77
404	207.3	330.1	607.6	0	1179.4	3.57	0	53.5	20.45
405	216.3	366	581	1127.9	0	4.2	0	126.1	30
406	204.8	435.7	564.3	1115.2	0	0	0	0	3.72
407	212.29	404	614	123	1105	0	0	0	34.2
408	212.72	404	614	0	1228	0	0	0	36.3
409	195	320	582	0	960	0	0	0	26.6
410	202	367	697	972	0	0	0	61	27.759
411	190	380	753.274	0	998.526	0	0	0	26.78
412	157.5	450	673.74	0	1099.26	0	0	0	28.18
413	187	425	653.055	0	1021.445	0	0	0	28.73
414	164.9	485	652.567	0	1020.683	0	0	0	30.22
415	190	380	745.712	0	949.088	0	0	0	25.25
416	157.5	450	673.92	1198.08	0	0	0	0	32.3
417	220	440	644	1096	0	0	0	0	35.1
418	220	367	725	0	1088	0	0	0	28.033
419	220	440	644	876.8	219.2	0	0	0	32.333
420	220	440	644	0	1096	0	0	0	30.6
421	200	500	578	897.6	224.4	0	0	0	35.533
422	220	367	725	0	1088	0	0	0	25.633
423	220	440	644	876.8	219.2	0	0	0	31.3
424	200	500	578	0	1122	0	0	0	31.9
425	220	367	725	870.4	217.6	0	0	0	28.567
426	220	440	644	0	1096	0	0	0	24.5
427	200	500	578	897.6	224.4	0	0	0	34.467
428	220	367	725	0	1088	0	0	0	20.567
429	220	440	644	876.8	219.2	0	0	0	28.9
430	200	500	578	0	1122	0	0	0	24.533

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