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Laboratory modeling of the vibration due to sawing carbonate and granite ornamental stones using statistical and soft computing methods

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Abstract

In this paper, vibration of cutting machine during sawing carbonate and granite ornamental stones was investigated through making a cutting machine on a laboratory scale. For this purpose, properties of 7 samples of carbonate stones and 5 samples of granite stones were measured and 211 sawing experiments were performed. Predictives models were developed using different variation of physical and mechanical parameters by incorporating statistical and intelligent methods. The performance of the developed models was evaluated using R^2, RMSE, MAPE and VAF criteria for two different types of test datasets consists of Type A and B; data type A included data for rock samples available at the learning stage and data type B included data for rock samples not available in the training phase. The best model for each group of rocks was introduced by taking rank aggregation based on the evaluation criteria, speed, easiness and reliability of developing method into account. Results indicated that the best model for both rock type was in the form of multivariate nonlinear regression. The similar parameters of these models were depth of cut, feed rate and Schmiazek abrasivity factor. In addition, Young's modulus and UCS were the special parameters in the carbonate and granite rock models, respectively. These special parameters were in accordance with the finding of sensitivity analysis results.

Keywords: *Ornamental stones, Rock cutting machine, Vibration, Laboratory modeling, Statistical methods, Soft computing methods*

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Extended Abstract:

1. Introduction

Forecasting and evaluating the performance of cutting ornamental stones can be a major step in understanding the process as well as evaluation of the performance of cutting machines. The performance evaluation of cutting machines is very important in estimating the costs and designing a ornamental stone cutting factory. Predicting the performance of cutting machines leads the designers to improve the processing speed and increase the production. System vibration is one of the main factors in the evaluation of sawing performance in a way that several parameters such as sawing quality, sawing tools wearing and energy consumption depend on it. Nowadays, there is precision equipment for recording the vibration in sawing process. However, for cost analysis and project planning it is necessary to predict this parameter.

Literature review showed that there are few studies in the predicting vibration during ornamental stones cutting process. Ozcelik et al. (2001) investigated the relationship between the cutting depth and the vibration. Mikaeil et al. (2011) studied the application of a fuzzy analytical hierarchy process to the prediction of vibration during the rock sawing process. Ozcelik and Yilmazkaia (2011) studied the effect of rock anisotropy on the vibration of cutting machines. The results obtained showed that the least vibration was achieved when the cutting angle along the z axis was 25 degrees. Mikaeil et al. (2014) investigated the relationship between the system vibrations and the rock brittleness indices in the rock sawing process using statistical method.

2. Materials and methods

Samples blocks of two groups of ornamental stones including 7 samples of carbonate stones and 5 samples of granite stones were collected from various quarries located in Iran. To determine their properties, experiments were carried out with high precision under the standards of the International Association of Rock Mechanics (ISRM, 1981) in the laboratory (Table 1).

Table 1 Physical and mechanical properties of the studied rocks

Name	EQC (%)	GS (mm)	MH (n)	UCS (MPa)	BTS (MPa)	YM (GPa)	SF-a (N/mm)
Ghermez Yazd (Granite)	57.65	2.90	6.10	142	8.52	43.60	14.24
Meshki Chayan (Granite)	60.06	0.87	6.60	173	15	48.60	7.60
Sefid Nehbandan(Granite)	64.30	4.10	5.95	145	9.20	35.50	24.25
Shokolati Khoramdareh (Granite)	32.20	3.90	5.65	133	8.30	28.90	10.42
Morvarid Mashhad (Granite)	30.30	3.80	5.60	125	7.40	31.20	8.50
Kerem Hersin (Marble)	3.60	0.55	3.50	71.50	6.80	32.50	0.14
Sourati Anarak (Marble)	3.40	0.45	3.2	74.50	7.10	33.60	0.11
Ghermez Azarshahr (Travertine)	2.80	1.01	2.9	53	4.30	20.70	0.12
Haji Abad (Travertine)	2.60	0.85	2.9	61.50	5.60	21	0.12
Dareh Bokhari (Travertine)	2.70	0.87	2.95	63	5.40	23.50	0.13
Salsali (Marble)	3.20	0.52	3.10	73	6.30	31.60	0.11
Sourati Haftouman (Marble)	4	0.60	3.60	74.50	7.20	35.50	0.17

EQC: Equivalent quartz content, Gs: Grain size, MH: Mohs hardness, UCS: Uniaxial compressive strength, BTS: Brazilian tensile strength, YM: Young's Modules,SF-a: Schmiazek F-abrasivity factor.

In order to predict the vibration of sawing system, experimental procedure was carried out using laboratory rock cutting machine. It consists of three major sub-systems, 1) a sawing unit, 2) instrumentation and 3) personal computer. Sawing operational parameters such as feed rate, depth of cut, and peripheral speed control in the monitoring system, and the results record in personal computer. In the laboratory, each dimension stone was sawn at different feed rates, i.e. 100, 200, 300, and 400 cm/min, and at depths of cut of 35, 30, 22, and 15 mm. Accordingly, 211 sawing experiments were performed. In order to develop predictive models, 75% of the total data was considered as the training data and the remaining 25% of data as the test data consists of Type A and B; data type A included data for rock samples available at the learning stage and data type B included data for rock samples not available in the training phase.

In the current study, statistics methods including linear and nonlinear multivariate regression models and soft computing methods including optimized support vector regression by cuckoo optimization algorithm (COA-SVR), multi-layered perceptron artificial neural network with back propagation algorithm optimized by genetic algorithm (GANN-BP) and general regression neural network (GRNN) with optimal Euclidean distance were applied to develop predictive models.

3. Results

After developing predictive models, 5 models which have the best performance in training step were selected to validate in the estimation of both categories of testing data types A and B, and compared with the measured values. For this purpose, four criteria were considered including the RMSE, the coefficient of determination (R^2), the proportion of variance accounted for (VAF), and the mean absolute percentage error (MAPE). Table 2 shows results of validation step.

Table 2 Performance of the developed models

Test data	Rock Type	Model	Evaluation Criteria			
			R^2	RMSE	MAPE	VAF
Type A	Carbonate (Kerem Hersin, Sourati Anarak, Ghermez Azarshahr, Haji Abad, Salsali, Sourati Haftouman)	Linear Regression	87.46	0.026	8.593	87.350
		Nonlinear Regression	94.53	0.018	5.432	94.453
		GANN-BP	91.96	0.023	6.963	91.496
		GRNN	95.37	0.016	5.867	95.351
		COA-SVR	96.48	0.019	8.349	96.462
	Granite (Meshki Chayan, Sefid Nehbandan, Shokolati Khoramdareh, Morvarid Mashhad)	Linear Regression	97.33	0.012	4.380	97.324
		Nonlinear Regression	96.32	0.015	4.726	96.166
		GANN-BP	97.27	0.024	8.762	95.068
		GRNN	90.87	0.023	7.577	90.713
		COA-SVR	95.81	0.032	9.880	86.952
Type B	Carbonate (Dareh Bokhari)	Linear Regression	97.40	0.014	6.230	94.179
		Nonlinear Regression	98.76	0.007	3.170	98.699
		GANN-BP	96.93	0.014	4.994	94.665
		GRNN	98.04	0.010	3.725	97.756
		COA-SVR	98.68	0.017	8.924	98.522
	Granite (Ghermez)	Linear Regression	88.32	0.059	15.701	82.163
		Nonlinear Regression	89.49	0.054	14.247	85.135
		GANN-BP	89.40	0.043	12.179	76.774
		GRNN	87.36	0.064	16.221	81.213
		COA-SVR	87.59	0.051	13.480	77.326

In order to select the best model in each group of ornamental stones, rank aggregation technique includes Copeland and Borda methods for performance of model (Table 3), speed, easiness and reliability of developing method were taken into account.

Table 3 Rank Aggregation of proposed models based on the performance criteria

Rock Type	Model	Average rank	Copeland Rank	Ultimate Rank
Carbonate	Linear Regression	4.5	5	4.75
	Nonlinear Regression	1.5	1	1.25
	GANN-BP	3.875	4	3.938
	GRNN	2.25	2	2.125
	COA-SVR	2.875	2	2.438
Granite	Linear Regression	2.125	1	1.563
	Nonlinear Regression	2.125	1	1.563
	GANN-BP	2.75	3	2.875
	GRNN	4.125	5	4.563
	COA-SVR	3.875	5	4.438

4. Conclusion

Predictive models to estimate vibration od cutting mashine during sawing ornamental stones were developed based on the laboratory expriment by incorporating statistics and soft computing methods. Based on results, the following conclusions could be drawn:

- Compressive strength, tensile strength, Young’s modulus, equivalent quartz content and Mohs hardness have a direct relationship with vibration whereas this relationship is indirect for the grain size. It was observed that there is no clear relationship between Schmiazek F-abrasivity factor and vibration. It was conculded that in carbonate stones correlation between depth of cut and vibration is very weak while there is no clear corelation in granite stones. In addition, it was observed direct relation ship between feed rate and vibration for both stones groups.
- Results indicated that the best model for both rock type was in the form of multivariate nonlinear regression. The similar parameters of these models were depth of cut, feed rate and Schmiazek abrasivity factor. In addition, Young’s modulus and UCS were the special parameters in the carbonate and granite rock models, respectively.
- Sensitivity analysis using cosine amplitude method (CAM) indicated that Young’s modulus and UCS are the most important parameter in amount of vibration for carbonate and granite ornamental stones, respectively.

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