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Araştırma Makalesi / Research Article

Investigation of the Relationships between Compressive Strength and Some Physical Parameters of Pyrite Containing Rocks

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Keywords
Pyrite content;
Rock strength;
Clemex;
Motorized table.

Abstract

This study focuses on the investigation of the relationships between physical parameters (cohesion (C), internal friction angle (ϕ), unit weight (UW), ultrasonic P wave velocity (UPV)) and pyrite content (Py, %) with rock strength (UCS). Polished section analyses of rocks were performed via Clemex image analysis system and motorized table which are integrated into the trinocular research microscope that is a modern technique. Correlation analysis was performed between UCS and Py. Statistically significant relation wasn't obtained between the data pairs even though coefficient of correlation is relatively high (r=0.69). However, a statistically significant relationship (with p=0.003 and F=302.6) was achieved with high coefficient of determination (R^2=0.936) when multivariate regression analysis was carried out between UCS and other parameters including "Py" used in this study.

Pirit İçerikli Kayaçların Basma Dayanımı ve Bazı Fiziksel Parametreleri Arasındaki İlişkilerin Araştırılması

Anahtar kelimeler
Pirit içeriği;
Kaya dayanımı;
Clemex;
Motorize tabla.

Öz

Bu çalışma, kayaçların fiziksel parametreleri (kohezyon (C), içsel sürtünme açısı (ϕ), birim hacim ağırlık (UW), ultrasonik P dalga hızı (UPV)) ve pirit içeriğinin (Py, %) kayaç basma dayanımı (UCS) ile arasındaki ilişkilerin incelenmesine odaklanmaktadır. Kayaçların parlak kesit analizleri, modern bir teknik olan trinoküler araştırma mikroskobuna entegre edilmiş Clemex görüntü analiz sistemi ve motorlu tabla ile gerçekleştirilmiştir. UCS ve Py arasında korelasyon analizi yapılmıştır. Korelasyon katsayısı (r=0.69) nispeten yüksek olmasına rağmen veri çiftleri arasında istatistik olarak anlamlı bir ilişki elde edilememiştir. Öte yandan, UCS ve bu çalışmada kullanılan pirit içeriği dahil diğer parametreler arasında çoklu regresyon analizi yapıldığında, istatistiksel açıdan önemli ve (p=0.003 and F=302.6) çok güçlü/yüksek determinasyon katsayısına (R^2=0.936) sahip tahmin modeli elde edilmiştir.

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1. Introduction

Determination of engineering properties of rocks is vital for the design of underground and open pit mining, tunneling and highways. Uniaxial compressive strength (UCS) of rock material has become one of the most important engineering parameters over the years. Therefore, many researchers have developed relationships between UCS and other test methods (Schmidt hammer, point load index (PLI), ultrasonic P wave velocity (UPV), etc.) when the UCS cannot performed directly (Fener et al. 2005; Kılıç and Teymen 2008; Mishra and Basu 2012; Singh et al. 2012; Kahraman 2001; Yagiz 2011; Karaman and Kesimal 2015a).

On the other hand, some researchers have investigated correlations between different parameters (unit weight – elastic modulus (Sonmez et al. 2004; Ocak 2008), elastic modulus – Schmidt hardness (Yilmaz and Sendir 2002), cohesion – Brazilian tensile strength (BTS) (Karaman et al. 2015). Karaman et al. (2015) haven't obtained meaningful relationships between internal friction angle (ϕ) and other engineering properties (UCS and BTS) of rock material. Further, Beyhan (2008) correlated ϕ values with the BTS and UCS for marl rocks from the Tunçbilek and Soma regions in Turkey. The author hasn't found reliable relation between ϕ – BTS and ϕ – UCS data pairs.

Mineral contents, texture (grain size and shape), fabric (voids) and the weathering condition affect the rock engineering properties (İrfan 1996; Tuğrul and Zarif 1999; Prikryl 2001). Some researchers have studied the effect of grain size on the mechanical characteristics of rocks (Brace 1961; Onodera and Asoka Kumara 1980). Brace (1961) indicated that rock strength is greater for finer grained rocks. Shakor and Bonelli (1991) found weak relationships between mechanical properties and grain size, percentage of the angular grains, packing density, sphericity, and amount of cement. Prikryl (2001) showed that the strength of granitic rocks decreased as the average grain sizes increased. Tuğrul and Zarif (1999) mentioned that the rock strength increases as the mean grain (quartz, plagioclase and feldspar) size decreases for granites.

Literature review shows that there is no study on the relationship between pyrite content and UCS of rock materials. The aim of this study is to investigate the relationships between UCS and some mineralogical (pyrite content) and physical properties (C, ϕ, UPV and UW) of rocks. Polished section analyses of rocks were also performed with Clemex image analysis system and motorized table which are integrated into the trinocular research microscope that is a modern technique.

2. Experimental Studies

Representative rock samples were taken from Çaykara/Trabzon city, north of Turkey. Detailed studies of engineering properties from these rocks were published elsewhere (Karaman and Kesimal 2015a, 2015b; Karaman et al. 2015). The names and engineering properties of the collected rocks are given in Table 1.

The rocks studied were classified according to their pyrite contents. A total of 8 pyrite-bearing representative rock samples were prepared for polished section analyses in the laboratory. Samples were cut with a diamond saw in 1.5 x 1.5 cm or 1.5 x 2 cm dimensions. Several different types of abrasive (grit size: 180, 320, 600, 800 and 1000) were used in the polishing process. Images related to polished section were given in Figure 1.

Table 1. Engineering properties of rocks (Karaman and Kesimal 2015a, 2015b; Karaman et al. 2015)

Sample no	Rock type	UCS (MPa)	C (MPa)	ϕ (°)	UPV (m/s)	UW kN/m^{3})
1	Basalt	107.0	21.0	47.0	5602	27.3
2	Metabasalt	133.0	28.0	44.5	4800	28.1
3	Basalt	100.0	20.7	45.0	5310	25.0
6	Dacite	66.0	12.0	49.0	3943	26.6
8	Basalt	125.0	25.0	47.0	4934	27.8
9	Limestone	75.0	15.0	50.0	3382	26.3
10	Dacite	94.0	20.0	44.0	3983	27.0
16	Basalt	75.0	14.0	49.0	4576	27.0

UCS: Uniaxial compressive strength, C: Cohesion, ϕ: Internal friction angle, UPV: P wave velocity, UW: Unit weight

Figure 1. Images related to polished section

Trinocular research microscope was utilized in the analysis of pyrite. Images related to sections were taken through the software of Clemex and analyzed entire section for pyrite content with the help of motorized table (Figure 2). In order to analysis of mineral content (pyrite) and grain diameter of the mineral, an analysis routine is selected, without programming required (Figure 2a). Button of color threshold is used for colorization of pyrite mineral (i.e. yellow) on the screen (Figure 2b). Additionally, required options (i.e. length and area) are selected from the object measure window (Figure 2c). After all image areas are evaluated according to the content and grain diameters of the selected mineral (pyrite), findings are obtained using analysis and results button.

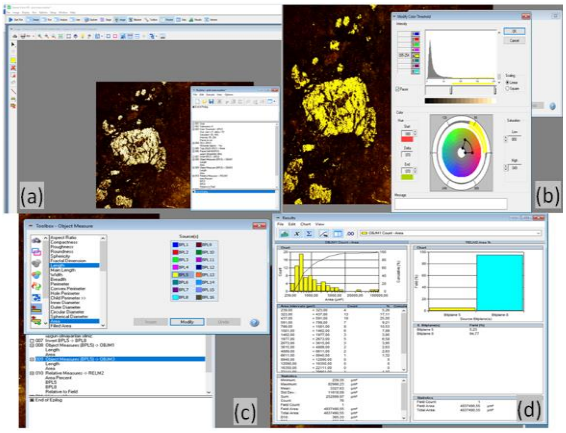

Figure 2. Images from Clemex

Pyrite contents and grain sizes of rock samples were illustrated in Table 2. The tested samples generally low fluctuations in pyrite contents ranging from 0.09 % to 0.87. While the smallest grain diameter of pyrite is measured as 24 µm, the largest grain diameter of pyrite is obtained as 895 µm. Average grain diameter of pyrite varied between 48 µm and 132 µm.

In this study, correlation and regression analyses were performed between UCS with pyrite content and other parameters (C, UPV, etc.). Findings were evaluated based on the SPSS v.17.0.

Table 2. Pyrite contents and grain sizes of samples

Sample no	Pyrite (%)	Smallest diameter (µm)	Largest diameter (µm)	Average diameter (µm)
1	0.45	24	402	94
2	0.09	43	447	132
3	0.68	33	526	65
6	0.81	42	163	78
8	0.46	33	570	80
9	0.87	34	102	48
10	0.58	33	526	73
16	0.33	33	895	79

3. Result and discussion

Figure 3 shows the polished sections of the samples including pyrite mineral. Pyrite grains which are concentrated in weakness zone or voids scattered throughout the whole section in a heterogeneous way. Pyrite content was obtained as 5.23 % when analyzing one image area (Figure 2d). However, average of the pyrite content was decreased to 0.33 when all image areas (80 pieces) were considered by using Clemex.

All rock data collected were normally distributed as can be seen from Table 3 with a significance range from 0.928-1.00. Correlation analysis is given in Figure 4 and histograms in Figure 5. A negative relation (r=-0.687) between UCS and pyrite content was observed although the correlation is insignificant (Sig.= 0.06) which is thought due to the insufficient number of sample (Figure 4). However, since the significance value of correlation is approximately at the statistical limit of confidence interval value (α=0.05), multiple regression analyses were performed between physical properties (C, ϕ, UPV and unit weight) and pyrite content (Py) (%) against rock's UCS for further investigation. Statistically significant regression model was obtained (with p=0.003 and F=302.59) among the data (Table 4, Table 5) with a coefficient of determination of 0.94 (Figure 6). Equation of the multiple regression model is given in Equation 1.

$$UCS = 4.32Py + 4.28C + 0.96\phi + 0.004\text{UPV} + 2.31\text{UW} - 114.46$$

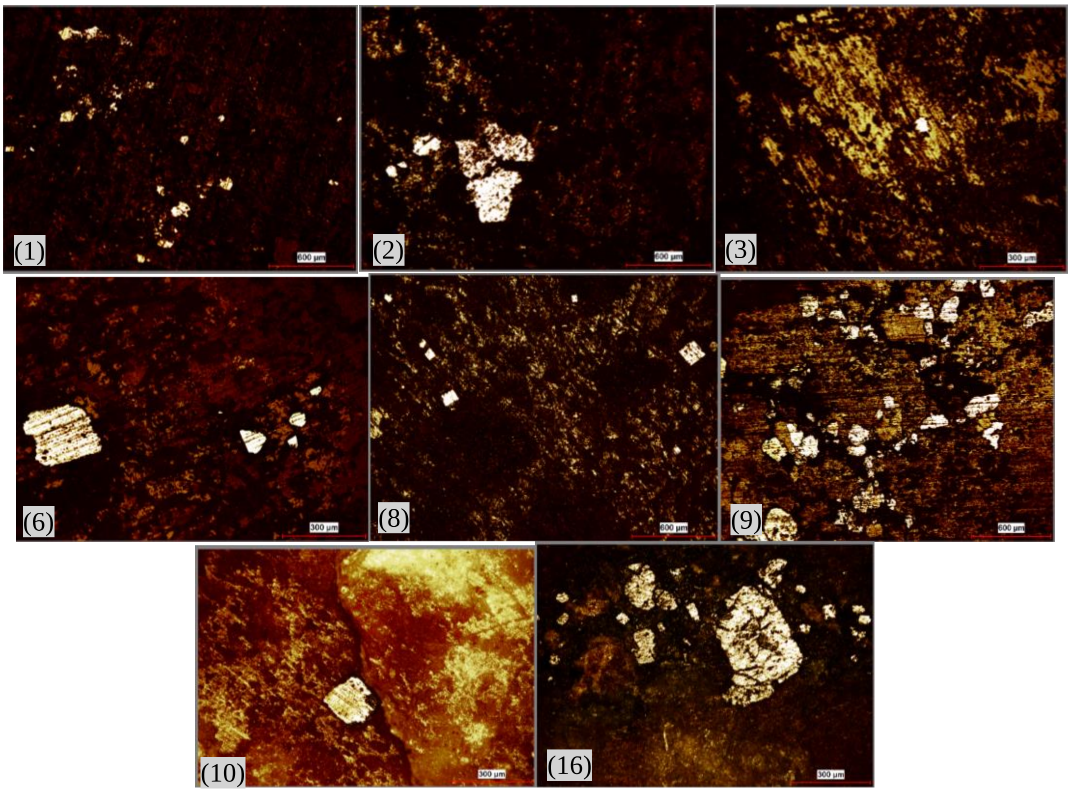

Figure 3. Images of the polished sections of the samples

All independent variables in the multiple regression model (Eq. 1 and Figure 6) contributed to the estimation of UCS about 93.6%. Further, the multicollinearity among the independent variables are moderate based on the variance inflation factor (VIF) ranged from 1.0 to 5.0 which is acceptable for regression analyses. VIF values of the independent variables also suggest that the regression model is stable. “C” is the most significant variable with a contribution degree of 73.32%. On the other hand, pyrite content which is lower than 1.0% in rock samples has a partial effect on UCS estimation of 3.47%. As can be seen from Eq. 1 that the pyrite content is not dominant parameter to determining of UCS values of sampled rocks.

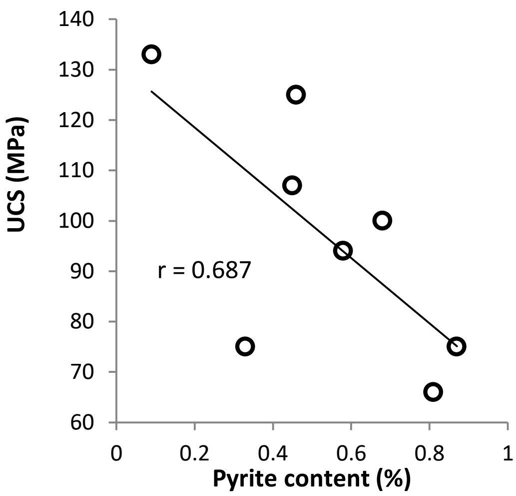

Figure 4. Relationship between UCS and Py

Table 3. Normalite analysis of the data

One-Sample Kolmogorov-Simirnov Test		Py	UCS	C	ϕ	UPV	UW
N		8	8	8	8	8	8
Normal Parameters[a,b]	Mean	0.5338	96.8750	19.4625	46.9375	4566.2500	26.8875
	Std. Deviation	0.25740	24.28072	5.51852	2.27467	750.90284	0.96279
Most Extreme Differences	Absolute	0.122	0.191	0.166	0.193	0.156	0.172
	Positive	0.113	0.191	0.166	0.178	0.156	0.104
	Negative	-0.122	-0.127	-0.164	-0.193	-0.130	-0.172
Kolmogorov-Simirnov Z		0.346	0.541	0.468	0.545	0.442	0.485
Asymp. Sig. (2-Tailed)		1.000	0.932	0.981	0.928	0.990	0.973

a. Test distribution is Normal.

Table 4. Regression model results (F and sig.)

ANOVA[b]					
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	4121.427	5	824.285	302.585	0.003[a]
Residual	5.448	2	2.724		
Total	4126.875	7			

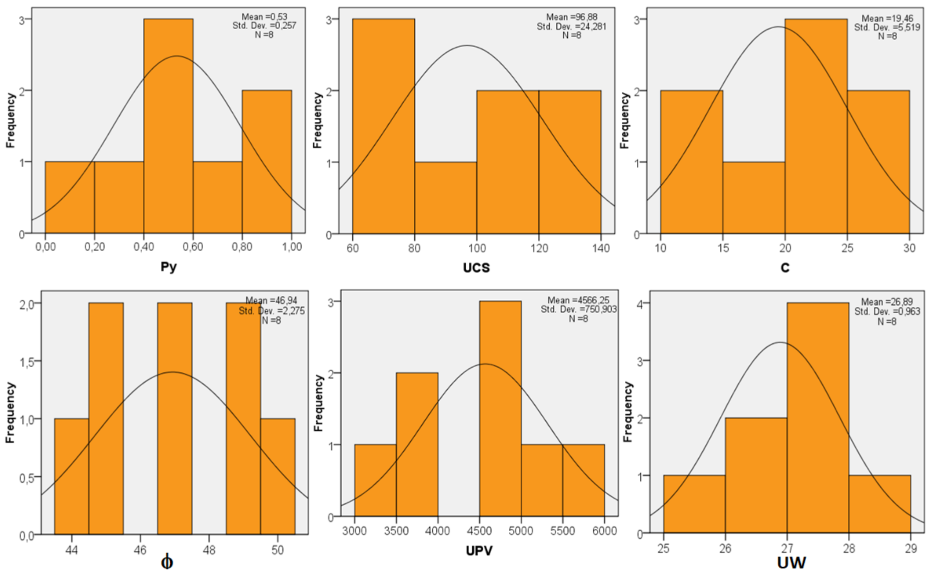

Figure 5. Histogram curves of the data

Table 5. Regression model results (Beta and VIF)

Model		Coefficients								
		Unstandardized Coefficients		Standardized Coefficients			95.0 % Confidence interval for B		Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	Constant	-114.457	33.021		-3.466	0.074	-256.534	27.620		
	Py	4.320	4.754	0.046	0.909	0.459	-16.134	24.774	0.260	3.847
	C	4.280	0.234	0.973	18.314	0.003	3.275	5.286	0.234	4.274
	ϕ	0.956	0.466	0.090	2.052	0.177	-1.048	2.959	0.347	2.882
	UPV	0.004	0.001	0.126	3.365	0.078	-0.001	0.009	0.468	2.136
	UW	2.314	1.190	0.092	1.944	0.191	-2.807	7.434	0.296	3.374

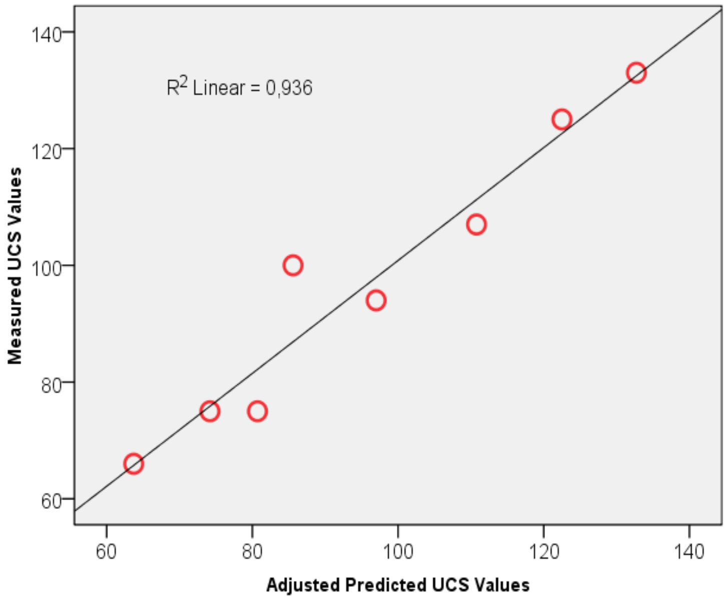

Figure 6. Correlation between the measured and predicted UCS values according to multivariate regression

In the literature, the relationships between mineralogical and engineering properties of rocks were mostly studied on granitic rocks (for quartz, plagioclase and feldspar) (Tuğrul and Zarif 1999; Sousa 2013). Some researchers stated that the rock strength increased as quartz content increased (Price 1960; Allen et al. 2014). However, inverse relation was obtained by Sousa (2013) between quartz content and strength of different Portuguese granites. In this study, it was shown that the pyrite which is likely to an impurity mineral has a partial effect of rock strength (3.47 %) since it exist with a small percentage within the rocks (< 1%). Pyrite grains can weaken the bonds of minerals that hold the rock grains together or most likely to cause disintegration within the weakness zones. Pyrite commonly crystallizes in the cubic system that makes it easier to break down under loading conditions. This study showed that performing the multivariate regression analysis is important for obtaining more reliable relations/estimation regression models among variables including mineral content i.e. pyrite minerals. However, further studies are needed to investigate the relationship between rock strength and content of pyrite which is higher than 1 %. Finally, modern methods such as Clemex and motorized table can be used efficiently since they provide reliable and rapid evaluation during the analyses (Karaman et al. 2017).

4. Conclusions

In order to investigate the relationship between UCS and Py, correlation analysis was performed. Although coefficient of correlation is relatively high (r=0.69), statistically insignificant relation (sig. =0.06) was seen between the data pairs. Since the sig. value for correlation is at the confidence interval limits due to the insufficient size of sample, multivariate regression analysis was carried out among UCS and other parameters (C, ϕ, UPV, UW and Py.) used in this study for further investigation. A significant multiple regression model was obtained (p=0.003 and F=302.6) with a very high and strong coefficient of determination (R^2=0.936).

Pyrite was found in small quantities (< 1 %) in the samples when averaging the whole section in Clemex. However, it reaches about 5% when considering a single image area. Pyrites concentrated in the weakness zones of rocks can make it easier to break under UCS test due to the it's structure.

This study indicated that pyrite content has a partial effect on the uniaxial compressive strength of rocks about 3.47 % as it is less than 1 %. Therefore, detailed studies are necessary for understanding the mechanism of pyrite content (>1%), which exists in the voids/weakness zones and homogeneous and/or heterogeneous mixture, in the estimation of UCS.

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