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RESEARCH ARTICLE

국내 골재의 물리적 특성 분석

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Physical Characterization of Domestic Aggregate

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Abstract

Aggregates from 84 cities and counties in Korea were tested for quality to allow analysis of the physical characteristics of aggregates from river, land, and forest environments. River and land aggregates were analyzed for 18 test items, and forest aggregates for 12 test items. They were classified according to watershed and geology, respectively. The observed physical characteristics of the river aggregates by basin were as follows: aggregates from the Geum River basin passed through 2.5, 1.2, 0.6, 0.3, 0.15, and 0.08 mm sieves; clay lumps constituted the Nakdong River basin material; aggregates from the Seomjin River basin passed through 10, 5, and 2.5 mm sieves; those from the Youngsang River basin passed through 1.2, 0.6, 0.3, 0.15, and 0.08 mm sieves; and aggregates from the Han River basin passed through 10, 5, 2.5, 1.2, 0.6, 0.3, and 0.08 mm sieves, Stability; Standard errors were analyzed for the average amount passing through 10, 0.6, and 0.08 mm silver sieves, and performance rate showed different distribution patterns from other physical characteristics. Analysis of variance found that 16 of the 18 items, excluding the absorption rate and the performance rate, had statistically significant differences in their averages by region. Considering land aggregates by basin, those from the Nakdong River basin excluding the Geum River basin had clay lumps, those from the Seomjin River basin had 10 and 5 mm sieve passage, aggregates from the Youngsang River basin had 0.08 mm sieve passage, and those from the Han River basin had 10, 0.6, and 0.08 mm sieve passage. The standard error of the mean of the quantity showed a different distribution pattern from the other physical characteristics. Analysis of variance found a statistically significant difference in the average of all 18 items by region. Analyzing forest aggregates by geology showed distributions of porosity patterns different from those of other physical characteristics in metamorphic rocks (but not igneous rocks), and distributions of wear rate and porosity were different from those of sedimentary rocks. There were statistically significant differences in the average volume mass, water absorption rate, wear rate, and Sc/Rc items by lipid.

Keywords: river aggregate, land aggregate, forest aggregate, quality test, watershed, geology, analysis of variance (ANOVA)

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초 록

골재자원조사를 통해 수집된 84개 시·군의 품질시험을 바탕으로 하천/육상/산림 골재의 물리적 특성값을 분석하였다. 하천/육상골재는 18개 시험 항목과 산림 골재는 12개 시험 항목에 대해 각각 유역과 지질에 따라 분류하였다. 물리적 특성으로 유역별 하천골재는 금강 유역이 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm, 0.08체 통과량과 낙동강유역은 점토덩어리와, 섬진강유역은 10 mm, 5 mm, 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm, 0.08체 통과량, 안정성과, 영산강유역은 10 mm, 5 mm, 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.08체 통과량과, 한강유역은 10 mm, 0.6 mm, 0.08체 통과량, 실적율이 평균의 표준오차가 다른 물리적 특성과는 다른 분포 양상을 보이는 것으로 분석됐다. 분산분석은 18개 항목 중 흡수율과 실적율을 제외한 16개 항목이 권역별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다. 또한, 유역별 육상골재는 금강유역을 제외한 낙동강유역이 점토덩어리와, 섬진강유역은 10 mm, 5 mm과, 영산강유역은 0.08체 통과량과, 한강유역은 10 mm, 0.6 mm, 0.08체 통과량이 평균의 표준오차가 다른 물리적 특성과는 다른 분포 양상을 보이는 것으로 분석됐다. 분산분석은 18개 항목 모두 권역별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다. 그리고, 지질별 산림골재는 화성암을 제외한 변성암이 공극률과, 퇴적암은 마모율과 공극률이 다른 물리적 특성과는 다른 분포 양상을 보이는 것으로 분석됐다. 분산분석은 표면건조밀도와 절대건조밀도, 진밀도, 단위용적질량, 흡수율, 마모율, 실리카중합비(Sc/Rc) 항목이 지질별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다.

주요어: 하천골재, 육상골재, 산림골재, 품질시험, 유역, 지질, 분산분석

서 론

골재는 도로, 철도, 항만, 공항 등 국가 사회 간접시설에서부터 주택과 같은 국민의 주거생활에 이르기까지 일상생활에 없어서는 안되는 필수적인 건설자재로서 국가건설의 기본이 되는 기초자재이다. 골재는 천연자원으로 각 시군에 따라 부존특성이 다르며, 골재자체의 사용물량과 그 중량으로 인해 원거리에서 조달이 힘들다는 특성이 있다. 사회간접자본으로서 골재 자원은 건설경제의 활성화로 인해 골재 수요는 계속 증가하는 추세인 반면, 자연환경의 보존과 인식의 확산으로 효과적인 골재채취에 많은 어려움이 뒤따르게 되었다. 건설재료 중 상당부분을 차지하는 콘크리트는 구성재료의 대부분이 대단히 중요하다고 할 수 있다. 일반적으로 골재의 성질은 골재의 입형과 입도 등과 이차적인 요소를 제외하면 천연골재와 쇄석골재를 막론하고 대부분이 원 암석의 성질에 좌우된다. 원암석의 성질은 성인과 생성메커니즘에 의해 다양하게 나타날 수 있는데, 이는 암석의 물성이나 역학적 특성 등과 같은 제반 특성에 많은 영향을 미친다. 또한 동일기원의 암석이라 할지라도 산출되는 지역에 따라 광물학적 및 역학적 특성에 다소 차이가 있을 수 있으며, 풍화 및 변질정도에 의해서도 다른 특성을 보일 수도 있다. 그러나 지금까지 보편적으로 행해져 왔던 콘크리트용 골재시험은 비중, 흡수율, 마모율, 안정성 등 주로 물리적 특성조사에만 국한되어져 왔으며, 이러한 품질 기준에만 적합하면 암석 고유의 광물학적 및 화학적 특성은 거의 무시한 채 어떤 용도의 골재로 사용하더라도 크게 문제시하지 않았다. 하지만 암석 고유의 특성을 감안하여 적합한 용도의 골재로 이용하기 위해서는 암석의 물리적·역학적 특성을 구명하기 전에 먼저 원암석의 광물학적 및 화학적인 특성을 이해하는 것이 무엇보다 중요하다고 할 수 있다(Jin et al., 1998). 따라서 이 연구의 목적은 골재자원조사 사업에서 도출된 전국의 골재 품질시험 결과를 바탕으로 하천/육상/산림골재의 물리적 특성값을 정리 분석함으로써 국내 골재의 분포 경향을 파악하는데 기본자료로 제공하고자 한다.

연구방법

2007~2021년까지 한국수자원공사와 한국지질자원연구원에서 수행된 84개 시·군의 골재자원조사(MCT and KORES, 2007; MCT and KIGAM, 2007a, 2007b, 2008; MLIT and K-water, 2014a, 2014b, 2015a, 2015b, 2016a, 2016b, 2017a, 2017b, 2017c, 2017d, 2018a, 2018b, 2018c; MLIT and K-water and KIGAM, 2017; MLIT and KIGAM, 2014, 2015,

2016, 2018a, 2018b, 2019a, 2019b, 2019c, 2019d, 2019e, 2020a, 2020b, 2020c, 2020d, 2020e, 2020f, 2021a, 2021b, 2021c, 2021d, 2021e, 2021f, 2021g; MLTMA and K-water and KORES, 2008; MLTMA and KORES, 2009; MLTMA and K-water, 2008, 2009a, 2009b, 2010a, 2010b, 2010c, 2010d, 2011a, 2011b, 2011c, 2011d, 2011e, 2012a, 2012b, 2012c, 2012d; MLTMA and KIGAM, 2008, 2009, 2010a, 2010b, 2010c, 2011, 2012a, 2012b, 2013a, 2013b, 2013c)에 대해 골재자원 정보시스템(Aggregate Resource Information System, 2011)을 통해 자료를 수집하였다. 또한, 조사위치 인근 하천정보에 대해서는 한국 하천열람(MOE, 2021)을 통해 하천연장을 파악하였고 위성사진(다음 지도)을 이용하여 하천 폭을 직접 측정하였다.

골재자원조사 결과 중 하천골재 1,118개소, 육상골재 1,828개소에 대해서는 시추조사, 시험굴조사, 물리탐사, 품질시험 등을 파악하였으며, 산림골재는 654개소에 대해 시추조사, 품질시험 자료를 수집하여 물리적(18개 항목) 특성을 분석하였다.

수집된 자료는 기본적으로 엑셀(excel) 프로그램에서 데이터베이스를 구축하였으며, 데이터를 바탕으로 표를 작성하였으며, 상관성 분석, 정규분포곡선 및 통계분석은 사회과학용 통계 패키지(statistical package for the social sciences, SPSS) 프로그램을 사용하여 수행하였다.

분석자료

수집한 자료는 하천골재 1,112개, 육상골재 1,828개, 산림골재 654개 등 총 3,594개 자료이다. 수집된 자료의 특성별 현황은 다음 Table 1과 같다.

Table 1. Data set (river aggregate, land aggregate, forest aggregate)

Category		River aggregate		Land aggregate		Category		Forest aggregate	
		Case	Ratio (%)	Case	Ratio (%)			Case	Ratio (%)
Total		1,112	100.0	1,828	100.0	Total		654	100.0
Area	Geumgang	158	14.2	349	19.1	Geological features	Metamorphic rock	238	36.4
	Nakdonggang	479	43.1	545	29.8		Sedimentary rock	93	14.2
	Seomjingang	23	2.1	156	8.5		Igneous rock	323	49.4
	Yeongsangang	151	13.6	274	15.0		Etc	8	1.2
	Hangang	301	27.1	504	27.6				

수집항목은 하천골재와 육상골재에서 물리적 특성 18개 항목, 산림골재에서 물리적 특성 12개 항목이다. 골재별 세부 항목은 Table 2와 같다.

Table 2. Measured properties (river aggregate, land aggregate, forest aggregate)

Category	Item (river aggregate, land aggregate)	Item (forest aggregate)
Physical properties (%)	10 mm / 5 mm / 2.5 mm / 1.2 mm / 0.6 mm / 0.3 mm / 0.15 mm / 0.08 sieve passing / Surface dry density (g/cm^3) / Absolute dry density (g/cm^3) / True density (g/cm^3) / Water absorption rate / Granulation rate / Stability / Clay mass / Unit mass (kg/l) / Chloride / Yield rate	0.08 sieve passing / Surface dry density (g/cm^3) / Absolute dry density (g/cm^3) / True density (g/cm^3) / Unit volume mass (kg/l) / Water absorption rate / Wear rate / Assembly rate / Performance rate / Porosity / Stability / Sc/Rc (alkaline aggregate reaction)

통계학적 분석방법

SPSS v22를 이용하여 통계분석을 실시하였으며, 기술통계(descriptive statistics), 분산분석(analysis of variance, ANOVA), 상관분석(correlation)을 실시하였다.

기술통계(descriptive statistics)로는 산술평균(mean), 평균의 표준오차(standard error of the means), 표준편차(standard deviation)를 분석하였다(Park and Yoon, 1997). 집단 간의 평균 차이에 대한 통계적 유의성을 검증하기 위해 분산분석(analysis of variance, ANOVA)을 실시하였다(Park and Yoon, 1997).

분산분석이란, 세 집단 이상의 평균치의 차이를 분석하고자 할 때 사용하는 분석방법으로 분산분석의 가설설정은 다음과 같다.

- 귀무가설(H0) : 각 집단의 평균은 동일하다($\mu_1 = \mu_2 = \ldots = \mu_n$).
- 대립가설(H1) : 각 집단의 평균은 차이가 있다($\mu_i \neq \mu_j$: 서로 다른 i, j에 대해 적어도 하나는 다름).

분산분석 그룹 내 분산과 그룹 간 분산을 가지고 산출한 F값(검정통계량)을 통해 가설을 검증한다. 그룹 내 분산(within groups sum of squares, SSW)은 각 집단의 평균치를 중심으로 그 집단에 속하는 측정치들이 얼마나 떨어져 있는 정도를 측정한 것으로 계산식은 다음 식 (1)과 같다.

$$SSW = \sum_j [\sum (X_{ij} - \overline{X_j})^2] \quad (1)$$

여기서, X_{ij} : j집단의 i표본의 측정치, $\overline{X_j}$: j집단의 평균

그룹 간 분산(between groups sum of squares, SSB)은 각 집단의 평균과 전체 평균의 떨어진 정도를 측정한 것으로 계산식은 다음 식 (2)와 같다.

$$SSB = \sum n_j (\overline{X}_{ij} - \overline{X_t})^2 \quad (2)$$

여기서, $\overline{X}_{ij}$: j집단의 i표본의 평균, $\overline{X_t}$: 전체 평균

총 분산(total groups sum of squares, SST)은 각 표본의 측정치들이 전체 평균으로부터 얼마나 떨어져 있는지를 측정한 것으로 계산식은 다음 식 (3)과 같다.

$$SST = \sum_i \sum_j (\overline{X}_{ij} - \overline{X_t})^2 \quad (3)$$

여기서, $\overline{X}_{ij}$: j집단의 i표본의 평균, $\overline{X_t}$: 전체 평균

즉, $SST = SSW + SSB$ (4)

검정통계량 F값은 그룹 간 변량과 그룹 내 변량의 비로 계산되며, 계산식은 다음 식 (5)와 같다.

$$F = \frac{MSB}{MSW} \quad (5)$$

여기서, $MSB = \frac{SSB}{df_B}$ (df_B : 집단 간 자유도 = 집단수 − 1)

$MSW = \frac{SSW}{df_W}$ (df_W : 집단 내 자유도 = 전체 사례수 − 집단수)

두 변수간의 연관성을 파악하기 위해 상관분석(correlation)을 실시하였다. 상관계수로는 피어슨 상관계수(Pearson's correlation coefficient)를 사용하였다(Yun, 2000).

상관분석이란, 두 변수 간에 얼마나 밀접한 선형관계를 가지고 있는지 분석하는 방법으로 선형관계의 정도를 나타내는 상관계수 계산식은 다음 식 (6)과 같다.

$$r = \frac{Cov(X, Y)}{Var(X)\,Var(Y)} = \frac{covariance\ of\ X, Y}{(standard\ deviation\ of\ X)(standard\ deviation\ of\ Y)} \quad (6)$$

여기서, $Cov(X, Y) = \sum(X_i - \overline{X})(Y_i - \overline{Y})$, $Var(X) = \sum(X_i - \overline{X})^2$, $Var(Y) = \sum(Y_i - \overline{Y})^2$

상관계수는 -1 < r < 1의 값을 가지며 1에 근접할수록 정(+)의 상관관계를, -1에 근접할수록 부(-)의 상관관계를, 0에 근접할수록 상관관계가 약하다는 것을 의미한다.

분석결과

유역권별 하천골재의 물리적 특성

하천골재의 물리적 특성 관련 18개 항목의 분포를 분석한 결과, 금강권역에서 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm, 0.08체 통과량과 낙동강권역의 점토덩어리, 섬진강권역의 10 mm, 5 mm, 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm, 0.08체 통과량, 안정성과 영산강권역에서 10 mm, 5 mm, 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.08체 통과량과 한강권역에서 10 mm, 0.6 mm, 0.08체 통과량, 실적율이 다른 물리적 특성과는 다른 분포의 양상을 보이는 것으로 분석됐다 (Tables 3~7).

5개 유역권별로 18개 물리적 특성 항목의 평균에 차이가 있는지 여부를 파악하기 위해 분산분석(ANOVA)을 실시한 결과, 18개 항목 중 흡수율과 실적율을 제외한 16개 항목이 권역별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다.

Table 3. Descriptive statistics of physical properties (river aggregate, Geumgang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	123	135	135	135	135	135	135	135	117
Mean	3.50	5.75	11.44	18.78	21.83	14.72	7.60	12.68	2.56
Std. error of the means	0.61	0.61	1.00	1.37	1.40	1.46	1.06	2.38	0.00
Std. deviation	6.71	7.07	11.67	15.86	16.24	17.02	12.34	27.60	0.04

Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Water absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	117	94	117	134	73	29	95	44	66
Mean	2.52	2.61	1.58	2.42	3.37	0.24	1.58	0.01	63.04
Std. error of the means	0.00	0.01	0.06	0.10	0.19	0.03	0.01	0.00	0.45
Std. deviation	0.05	0.05	0.63	1.16	1.60	0.18	0.09	0.01	3.64

Table 4. Descriptive statistics of physical properties (river aggregate, Nakdonggang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	392	435	435	416	416	416	416	470	427
Mean	5.19	5.86	8.84	14.71	17.74	18.63	11.33	13.15	2.53
Std. error of the means	0.59	0.45	0.57	0.81	0.83	0.96	0.63	0.98	0.00
Std. deviation	11.74	9.48	11.90	16.56	16.96	19.66	12.86	21.26	0.09

Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Water absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	461	165	428	442	421	243	188	289	36
Mean	2.51	2.54	1.74	2.38	2.73	12.33	1.54	0.01	62.19
Std. error of the means	0.01	0.01	0.05	0.06	0.09	1.58	0.01	0.00	0.73
Std. deviation	0.11	0.07	1.05	1.20	1.80	24.69	0.15	0.02	4.37

Table 5. Descriptive statistics of physical properties (river aggregate, Seomjingang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	14	16	16	16	16	16	16	18	19
Mean	10.52	14.40	26.72	25.96	15.56	4.97	3.13	3.80	2.46
Std. error of the means	1.85	1.91	2.96	2.29	2.91	1.72	1.03	1.27	0.02
Std. deviation	6.92	7.63	11.83	9.16	11.65	6.89	4.11	5.40	0.07

Table 5. Continued

Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Water absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	19	19	19	19	10	0	0	0	0
Mean	2.41	2.53	1.89	3.48	3.63	-	-	-	-
Std. error of the means	0.02	0.01	0.15	0.14	1.03	-	-	-	-
Std. deviation	0.08	0.06	0.66	0.63	3.27	-	-	-	-

Table 6. Descriptive statistics of physical properties (river aggregate, Yeongsangang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	109	125	125	125	125	125	125	95	95
Mean	8.72	14.05	14.35	17.27	20.85	11.91	3.80	14.24	2.55
Std. error of the means	1.34	1.53	1.24	1.11	1.69	1.09	0.37	2.37	0.01
Std. deviation	14.03	17.06	13.88	12.46	18.86	12.15	4.12	23.14	0.06
Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Water absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	95	62	95	102	91	33	68	35	49
Mean	2.50	2.61	1.67	3.02	4.71	1.43	1.60	0.04	62.53
Std. error of the means	0.01	0.01	0.08	0.14	0.59	0.20	0.02	0.01	0.48
Std. deviation	0.09	0.05	0.79	1.38	5.60	1.17	0.13	0.06	3.38

Table 7. Descriptive statistics of physical properties (river aggregate, Hangang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	78	243	243	243	243	243	243	273	257
Mean	3.62	12.93	17.23	22.03	23.84	9.30	4.56	7.11	2.56
Std. error of the means	1.12	0.88	0.97	0.97	1.35	0.64	0.54	1.10	0.00
Std. deviation	9.90	13.70	15.07	15.07	21.07	10.05	8.40	18.23	0.06
Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Water absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	258	195	257	274	252	89	84	65	38
Mean	2.53	2.63	1.71	2.77	3.76	0.96	1.58	0.01	64.09
Std. error of the means	0.00	0.00	0.05	0.06	0.17	0.14	0.02	0.00	1.01
Std. deviation	0.08	0.05	0.82	1.06	2.74	1.29	0.15	0.01	6.20

유역권별 10 mm, 5 mm, 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm, 0.08체 통과량, 표면건조밀도, 절대건조밀도, 진밀도, 조립률, 안정성, 점토덩어리, 단위용적질량, 염화물도 통계적으로 유의한 차이가 있는 것으로 나타났다. 한편, 유역권별 흡수율과 실적율은 통계적으로 유의한 차이가 있다고 할 수 없는 것으로 나타났다(Table 8).

Table 8. ANOVA of physical properties by area (river aggregate)

		Sum of squares	df	Mean square	F	Sig.
10 mm	Between groups (combined)	2,280.224	4	570.056	4.563	.001
	Within groups	88,834.997	711	124.944		
	Total	91,115.222	715			
5 mm	Between groups (combined)	13,093.013	4	3,273.253	24.249	.000
	Within groups	128,098.733	949	134.983		
	Total	141,191.745	953			
2.5 mm	Between groups (combined)	15,055.876	4	3,763.969	22.238	.000
	Within groups	160,622.651	949	169.255		
	Total	175,678.526	953			
1.2 mm	Between groups (combined)	9,525.913	4	2,381.478	9.934	.000
	Within groups	222,941.516	930	239.722		
	Total	232,467.429	934			
0.6 mm	Between groups (combined)	6,477.850	4	1,619.463	4.886	.001
	Within groups	308,278.814	930	331.483		
	Total	314,756.664	934			
0.3 mm	Between groups (combined)	15,971.193	4	3,992.798	15.306	.000
	Within groups	242,610.065	930	260.871		
	Total	258,581.257	934			
0.15 mm	Between groups (combined)	10,070.742	4	2,517.686	21.595	.000
	Within groups	108,425.191	930	116.586		
	Total	118,495.934	934			
0.08 sieve passing	Between groups (combined)	8,481.408	4	2,120.352	4.592	.001
	Within groups	455,268.021	986	461.732		
	Total	463,749.429	990			
Surface dry density (g/cm^3)	Between groups (combined)	.279	4	.070	12.296	.000
	Within groups	5.167	910	.006		
	Total	5.446	914			
Absolute dry density (g/cm^3)	Between groups (combined)	.265	4	.066	7.498	.000
	Within groups	8.360	945	.009		
	Total	8.625	949			
True density (g/cm^3)	Between groups (combined)	.900	4	.225	66.140	.000
	Within groups	1.802	530	.003		
	Total	2.702	534			
Water absorption rate	Between groups (combined)	3.039	4	.760	.916	.454
	Within groups	755.124	911	.829		
	Total	758.162	915			

Table 8. Continued

		Sum of squares	df	Mean square	F	Sig.
Assembly rate	Between groups (combined)	67.131	4	16.783	12.250	.000
	Within groups	1323.397	966	1.370		
	Total	1390.528	970			
Stability	Between groups (combined)	369.954	4	92.488	12.284	.000
	Within groups	6,339.726	842	7.529		
	Total	6,709.680	846			
Lump of clay	Between groups (combined)	12,144.310	3	4,048.103	10.690	.000
	Within groups	147,681.186	390	378.670		
	Total	159,825.497	393			
Unit volume mass (kg/l)	Between groups (combined)	.240	3	.080	4.478	.004
	Within groups	7.687	431	.018		
	Total	7.926	434			
Chloride	Between groups (combined)	.043	3	.014	31.521	.000
	Within groups	.194	429	.000		
	Total	.237	432			
Performance rate	Between groups (combined)	79.755	3	26.585	1.405	.243
	Within groups	3,499.486	185	18.916		
	Total	3,579.241	188			

유역권별 육상골재의 물리적 특성

육상골재의 물리적 특성 관련 18개 항목의 분포를 분석한 결과, 금강권역은 18개 항목 중 물리적 특성이 다른 분포 양상을 보이는 것이 없으나, 낙동강권역의 점토덩어리, 섬진강권역의 10 mm, 5 mm, 영산강권역의 0.08체 통과량, 한강권역에서 10 mm, 0.6 mm, 0.08체 통과량은 다른 물리적 특성과는 다른 분포의 양상을 보이는 것으로 분석됐다(Tables 9~13).

Table 9. Descriptive statistics of physical properties (land aggregate, Geumgang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	191	233	233	233	233	233	233	268	265
Mean	5.76	10.52	14.65	19.04	19.25	12.56	8.44	4.90	2.58
Std. error of the means	0.67	0.58	0.62	0.58	0.70	0.61	0.58	0.47	0.00
Std. deviation	9.30	8.90	9.48	8.84	10.62	9.25	8.79	7.76	0.07

Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	262	169	267	238	157	91	112	122	65
Mean	2.54	2.63	1.64	2.96	3.90	3.52	1.70	0.01	67.23
Std. error of the means	0.00	0.00	0.04	0.04	0.16	0.33	0.02	0.00	0.29
Std. deviation	0.08	0.05	0.67	0.63	1.94	3.15	0.18	0.05	2.35

Table 10. Descriptive statistics of physical properties (land aggregate, Nakdonggang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	219	325	325	294	294	294	294	448	391
Mean	6.51	9.90	10.39	13.31	14.45	15.10	12.57	12.25	2.55
Std. error of the means	0.78	0.61	0.53	0.67	0.66	0.68	0.78	0.99	0.00
Std. deviation	11.50	10.95	9.50	11.42	11.24	11.60	13.35	20.86	0.08
Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	423	222	395	366	294	193	158	209	49
Mean	2.52	2.58	1.44	2.45	2.79	16.81	1.63	0.01	62.98
Std. error of the means	0.01	0.01	0.04	0.05	0.11	1.90	0.02	0.00	0.65
Std. deviation	0.13	0.08	0.76	1.04	1.82	26.33	0.20	0.02	4.56

Table 11. Descriptive statistics of physical properties (land aggregate, Seomjingang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	16	84	84	84	84	84	84	119	114
Mean	12.94	14.00	17.73	19.91	20.43	14.34	7.23	4.46	2.50
Std. error of the means	2.05	1.09	0.76	0.74	0.76	0.78	0.45	0.84	0.01
Std. deviation	8.19	9.99	6.93	6.80	6.93	7.12	4.10	9.18	0.06
Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	114	110	114	119	60	4	4	20	0
Mean	2.46	2.53	1.26	2.72	2.42	2.43	1.68	0.00	-
Std. error of the means	0.01	0.01	0.09	0.06	0.17	0.24	0.07	0.00	-
Std. deviation	0.12	0.11	0.92	0.68	1.35	0.47	0.14	0.00	-

Table 12. Descriptive statistics of physical properties (land aggregate, Yeongsangang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	135	188	188	188	188	188	188	169	153
Mean	5.22	16.03	17.79	22.88	17.04	9.68	4.16	10.97	2.49
Std. error of the means	0.41	0.93	0.65	0.86	0.68	0.48	0.26	1.20	0.01
Std. deviation	4.78	12.80	8.93	11.77	9.30	6.56	3.62	15.62	0.10

Table 12. Continued

Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	153	122	153	168	156	20	50	36	31
Mean	2.45	2.56	2.24	3.01	3.21	1.18	2.03	0.08	62.92
Std. error of the means	0.01	0.01	0.10	0.07	0.28	0.20	0.07	0.02	0.67
Std. deviation	0.14	0.09	1.25	0.89	3.47	0.88	0.46	0.12	3.74

Table 13. Descriptive statistics of physical properties (land aggregate, Hangang)

Category	10 mm	5 mm	2.5 mm	1.2 mm	0.6 mm	0.3 mm	0.15 mm	0.08 sieve passing	Surface dry density (g/cm^3)
Case (N)	172	274	274	274	274	274	274	353	343
Mean	14.19	11.27	10.98	18.14	19.71	11.02	5.57	8.64	2.58
Std. error of the means	1.68	0.75	0.55	0.93	1.06	0.51	0.31	1.04	0.00
Std. deviation	22.06	12.42	9.04	15.44	17.47	8.44	5.19	19.45	0.06
Category	Absolute dry density (g/cm^3)	True density (g/cm^3)	Absorption rate	Assembly rate	Stability	Lump of clay	Unit volume mass (kg/l)	Chloride	Performance rate
Case (N)	344	197	343	372	337	151	62	152	25
Mean	2.55	2.62	1.64	3.08	4.11	2.04	1.76	0.00	64.49
Std. error of the means	0.00	0.00	0.04	0.06	0.24	0.14	0.03	0.00	0.98
Std. deviation	0.07	0.07	0.71	1.24	4.38	1.70	0.21	0.00	4.91

5개 유역권별로 18개 물리적 특성 항목의 평균에 차이가 있는지 여부를 파악하기 위해 분산분석(ANOVA)을 실시한 결과, 18개 항목 모두 유역권별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다(Table 14).

Table 14. ANOVA of physical properties by area (land aggregate)

		Sum of squares	df	Mean square	F	Sig.
10 mm	Between groups (combined)	9,481.145	4	2,370.286	13.015	.000
	Within groups	132,582.836	728	182.119		
	Total	142,063.980	732			
5 mm	Between groups (combined)	5,402.281	4	1,350.570	10.735	.000
	Within groups	138,267.689	1,099	125.812		
	Total	143,669.970	1,103			
2.5 mm	Between groups (combined)	10,094.169	4	2,523.542	30.374	.000
	Within groups	91,307.130	1,099	83.082		
	Total	101,401.298	1,103			
1.2 mm	Between groups (combined)	11,518.925	4	2,879.731	20.331	.000
	Within groups	151,273.118	1,068	141.641		
	Total	162,792.043	1,072			

Table 14. Continued

		Sum of squares	df	Mean square	F	Sig.
0.6 mm	Between groups (combined)	5,480.765	4	1,370.191	8.781	.000
	Within groups	166,651.739	1,068	156.041		
	Total	172,132.504	1,072			
0.3 mm	Between groups (combined)	4,376.395	4	1,094.099	12.845	.000
	Within groups	90,965.625	1,068	85.174		
	Total	95,342.020	1,072			
0.15 mm	Between groups (combined)	10,626.645	4	2,656.661	34.887	.000
	Within groups	81,327.655	1,068	76.149		
	Total	91,954.300	1,072			
0.08 sieve passing	Between groups (combined)	12,368.049	4	3,092.012	10.595	.000
	Within groups	394,575.402	1,352	291.846		
	Total	406,943.451	1,356			
Surface dry density (g/cm^3)	Between groups (combined)	1.502	4	.375	63.531	.000
	Within groups	7.453	1,261	.006		
	Total	8.955	1,265			
Absolute dry density (g/cm^3)	Between groups (combined)	1.612	4	.403	34.869	.000
	Within groups	14.920	1,291	.012		
	Total	16.532	1,295			
True density (g/cm^3)	Between groups (combined)	.953	4	.238	37.659	.000
	Within groups	5.155	815	.006		
	Total	6.108	819			
Water absorption rate	Between groups (combined)	87.172	4	21.793	32.322	.000
	Within groups	854.266	1,267	.674		
	Total	941.437	1,271			
Assembly rate	Between groups (combined)	87.902	4	21.976	22.196	.000
	Within groups	1,245.517	1,258	.990		
	Total	1,333.419	1,262			
Stability	Between groups (combined)	382.022	4	95.506	9.561	.000
	Within groups	9,978.830	999	9.989		
	Total	10,360.853	1,003			
Lump of clay	Between groups (combined)	23,110.672	4	5,777.668	19.507	.000
	Within groups	134,467.703	454	296.184		
	Total	157,578.374	458			
Unit volume mass (kg/l)	Between groups (combined)	6.421	4	1.605	26.859	.000
	Within groups	22.773	381	.060		
	Total	29.194	385			
Chloride	Between groups (combined)	.181	4	.045	29.750	.000
	Within groups	.812	534	.002		
	Total	.993	538			
Performance rate	Between groups (combined)	657.646	3	219.215	15.470	.000
	Within groups	2,352.334	166	14.171		
	Total	3,009.979	169			

지질별 산림골재의 물리적 특성

산림골재의 물리적 특성 관련 12개 항목의 분포를 분석한 결과, 변성암은 공극률, 퇴적암은 마모율과 공극률이 다른 물리적 특성과는 다른 분포의 양상을 보이는 것으로 분석됐다(Tables 15~17).

Table 15. Descriptive statistics of physical properties (forest aggregate, metamorphic rock)

Category	0.08 sieve passing	Surface dry density (g/cm^3)	Absolute dry density (g/cm^3)	True density (g/cm^3)	Unit volume mass (kg/l)	Absorption rate
Case (N)	152	224	231	142	153	231
Mean	0.65	2.67	2.65	2.73	1.52	1.10
Std. error of the means	0.09	0.01	0.01	0.01	0.01	0.05
Std. deviation	1.05	0.09	0.09	0.10	0.11	0.72
Category	Wear rate	Assembly rate	Performance rate	Porosity	Stability	Sc/Rc
Case (N)	202	117	154	167	208	131
Mean	22.11	7.48	57.34	37.00	3.64	1.19
Std. error of the means	0.60	0.09	0.24	1.11	0.23	0.13
Std. deviation	8.48	1.02	3.01	14.39	3.39	1.51

Table 16. Descriptive statistics of physical properties (forest aggregate, sedimentary rock)

Category	0.08 sieve passing	Surface dry density (g/cm^3)	Absolute dry density (g/cm^3)	True density (g/cm^3)	Unit volume mass (kg/l)	Absorption rate
Case (N)	61	87	87	62	62	87
Mean	0.80	2.65	2.62	2.71	1.49	1.32
Std. error of the means	0.23	0.01	0.01	0.01	0.01	0.10
Std. deviation	1.78	0.09	0.10	0.08	0.11	0.90
Category	Wear rate	Assembly rate	Performance rate	Porosity	Stability	Sc/Rc
Case (N)	79	55	61	68	79	55
Mean	20.80	7.52	56.80	38.63	4.91	0.38
Std. error of the means	1.34	0.09	0.50	1.64	0.67	0.04
Std. deviation	11.90	0.69	3.88	13.52	5.99	0.33

Table 17. Descriptive statistics of physical properties (forest aggregate, igneous rock)

Category	0.08 sieve passing	Surface dry density (g/cm^3)	Absolute dry density (g/cm^3)	True density (g/cm^3)	Unit volume mass (kg/l)	Absorption rate
Case (N)	180	283	277	192	186	297
Mean	0.83	2.62	2.60	2.67	1.47	1.24
Std. error of the means	0.08	0.00	0.01	0.00	0.01	0.05
Std. deviation	1.02	0.07	0.08	0.06	0.10	0.84

Table 17. Continued

Category	Wear rate	Assembly rate	Performance rate	Porosity	Stability	Sc/Rc
Case (N)	284	119	196	199	281	140
Mean	24.40	7.55	56.94	39.15	4.33	1.04
Std. error of the means	0.64	0.05	0.24	0.90	0.30	0.11
Std. deviation	10.84	0.55	3.36	12.72	5.09	1.28

3개 지질별로 12개 물리적 특성 항목의 평균에 차이가 있는지 여부를 파악하기 위해 분산분석(ANOVA)을 실시한 결과 표면건조밀도와 절대건조밀도, 진밀도, 단위용적질량, 흡수율, 마모율, Sc/Rc 항목은 지질별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다(Table 18).

Table 18. ANOVA of physical properties by geological features (forest aggregate)

		Sum of squares	df	Mean square	F	Sig.
0.08 sieve passing	Between groups (combined)	2.853	2	1.426	1.025	.360
	Within groups	542.482	390	1.391		
	Total	545.335	392			
Surface dry density (g/cm^3)	Between groups (combined)	.288	2	.144	21.739	.000
	Within groups	3.920	591	.007		
	Total	4.208	593			
Absolute dry density (g/cm^3)	Between groups (combined)	.326	2	.163	19.655	.000
	Within groups	4.906	592	.008		
	Total	5.231	594			
True density (g/cm^3)	Between groups (combined)	.333	2	.166	25.299	.000
	Within groups	2.584	393	.007		
	Total	2.917	395			
Unit volume mass (kg/l)	Between groups (combined)	.270	2	.135	12.134	.000
	Within groups	4.435	398	.011		
	Total	4.705	400			
Water absorption rate	Between groups (combined)	4.053	2	2.026	3.104	.046
	Within groups	399.531	612	.653		
	Total	403.584	614			
Wear rate	Between groups (combined)	1,097.048	2	548.524	5.246	.006
	Within groups	58,761.171	562	104.557		
	Total	59,858.219	564			
Assembly rate	Between groups (combined)	.333	2	.166	.265	.768
	Within groups	181.148	288	.629		
	Total	181.481	290			
Performance rate	Between groups (combined)	18.728	2	9.364	.851	.428
	Within groups	4,491.841	408	11.009		
	Total	4,510.569	410			

Table 18. Continued

		Sum of squares	df	Mean square	F	Sig.
Porosity	Between groups (combined)	434.342	2	217.171	1.190	.305
	Within groups	78,646.521	431	182.475		
	Total	79,080.863	433			
Stability	Between groups (combined)	109.547	2	54.773	2.491	.084
	Within groups	12,421.719	565	21.985		
	Total	12,531.266	567			
Sc/Rc	Between groups (combined)	25.837	2	12.919	7.865	.000
	Within groups	530.563	323	1.643		
	Total	556.400	325			

결 론

2007~2021년까지 수행된 84개 시 · 군의 골재자원조사(한국수자원공사, 한국지질자원연구원)를 통해 수집된 품질시험 결과를 바탕으로 하천/육상/산림 골재의 물리적 특성값을 정리 분석하였다.

조사 결과 중 시추조사, 시험굴조사, 물리탐사, 품질시험 등에서 하천골재 1,118개, 육상골재 1,828개 자료를 수집하고, 산림골재는 시추조사를 통해 654개 자료를 수집하였다.

하천/육상골재는 18개 시험 항목에 대해 유역에 따라 구분하였고, 산림골재는 12개 시험항목에 대해서는 지질로 분류하여 분석하였다.

하천골재의 물리적 특성 관련 18개 항목의 분포를 분석한 결과, 금강유역에서는 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm, 0.08체 통과량과 낙동강유역에서는 점토덩어리와 섬진강유역에서는 10 mm, 5 mm, 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm, 0.08체 통과량, 안정성과, 영산강유역에서는 10 mm, 5 mm, 2.5 mm, 1.2 mm, 0.6 mm, 0.3 mm, 0.08체 통과량과 한강유역에서는 10 mm, 0.6 mm, 0.08체 통과량, 실적율이 평균의 표준오차가 다른 물리적 특성과는 다른 분포의 양상을 보이는 것으로 분석됐다. 분산분석 결과, 18개 항목 중 흡수율과 실적율을 제외한 16개 항목이 권역별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다.

또한, 유역별 육상골재에 대한 물리적 특성은 금강유역을 제외한 낙동강유역에서는 점토덩어리와 섬진강유역에서는 10 mm, 5 mm과, 영산강유역에서는 0.08체 통과량과 한강유역에서는 10 mm, 0.6 mm, 0.08체 통과량이 평균의 표준오차가 다른 물리적 특성과는 다른 분포의 양상을 보이는 것으로 분석됐다. 분산분석 결과, 18개 항목 모두 권역별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다.

지질별 산림골재의 물리적 특성 관련 12개 항목의 분포를 분석 결과, 화성암을 제외한 변성암은 공극률과 퇴적암은 마모율과 공극률이 다른 물리적 특성과는 다른 분포의 양상을 보이는 것으로 분석됐다. 분산분석 결과, 표면건조밀도와 절대건조밀도, 진밀도, 단위용적질량, 흡수율, 마모율, Sc/Rc(알카리골재반응) 항목은 지질별로 평균에 통계적으로 유의한 차이가 있는 것으로 분석됐다.

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