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The Effect of Gradation and Grain-Size Properties of Fine Aggregate on the Building Mortars

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Abstract

This work is about the effect of fine aggregate properties on the physicomechanical characteristics of hardened mortars. The results indicated that the increase in grain-size of fine aggregate increases the bulk density of hardened mortars. The strength of mortars including limestone fine aggregate is higher than that of the silica-sand. Regardless of the aggregate origin, the strength of the mortars with well-graded fine aggregate for all grain-size is greater than of with uniform fine aggregate. This indicates that grading of fine aggregate increases the strength, while uniformity decreases it.

The strength of mortars with well-graded fine aggregate increases as the grain-size increases. Regardless of the aggregate origin, the strength of mortars with uniform fine aggregate increases with increasing grain-size until the grain-size range of 425-1000 µm, but after this range it decreases with increasing grain-size. The thermal conductivity increases with the increase in the grain-size. Notedly, the relationship between thermal conductivity and maximum grain-size of well-graded fine aggregate has a very strong positive correlation. Further, the thermal conductivity value for mortars formed with uniform fine limestone aggregate is minimum at the grain-size range of 425-1000 µm, while it has greatest values close together from this grain-size range

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1. Introduction

Fine aggregate as filling material with cement makes up approximately 90-99% of building mortars. Filling materials can be defined as fine aggregate grade materials with or without binder. Filling materials brought to desired dimensions using crushers and sieves; in other words, it is inevitable to find stone dust (micronized aggregate) passing through 75µm sieve in crushed sand (Ramyar et al., 1995). This size of material is also called stone dust.

There are not many studies on the effects of micronized aggregate or stone dust on building materials. It has been determined that fine aggregate up to a certain amount has a positive effect on the strength and insulation of concrete (Ramyar et al., 1995; Özgan, 2008). Şahin 2011, indicated that the micronized pumice had a positive effect on the strength of a very special size composite plaster.

In this study, the effects of type and grain size distribution, which are the main components of building mortars, on the long-short term physicomechanical properties are revealed. For this purpose, the effects of grain-size distribution variation on changes in physicomechanical characteristics of hardened mortars were investigated by using limestone and silica-sand fine aggregates as filling materials. Few studies are available to determine the effects of the grain size and distribution of fine aggregate on the physicomechanical properties of building mortar. In this research, an experimental research was carried out in line with the objectives mentioned above.

2. Experimental material

Karaisalı limestone taken from the region of Adana city (south Turkey) and silica-sand taken from the Silis Maden company located in Tarsus (south Turkey) were used as the material in the study (Fig 1 and 2). The limestone aggregate and silica-sand micronized by grinding in the crusher are well-graded (Fig. 3).

Fig. 1. Micronized silica sand

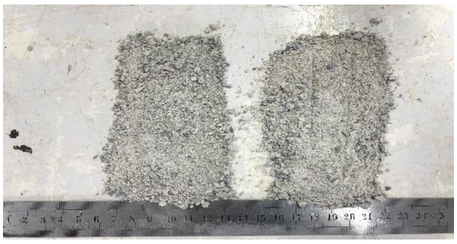

Fig. 2. Mikronized limestone

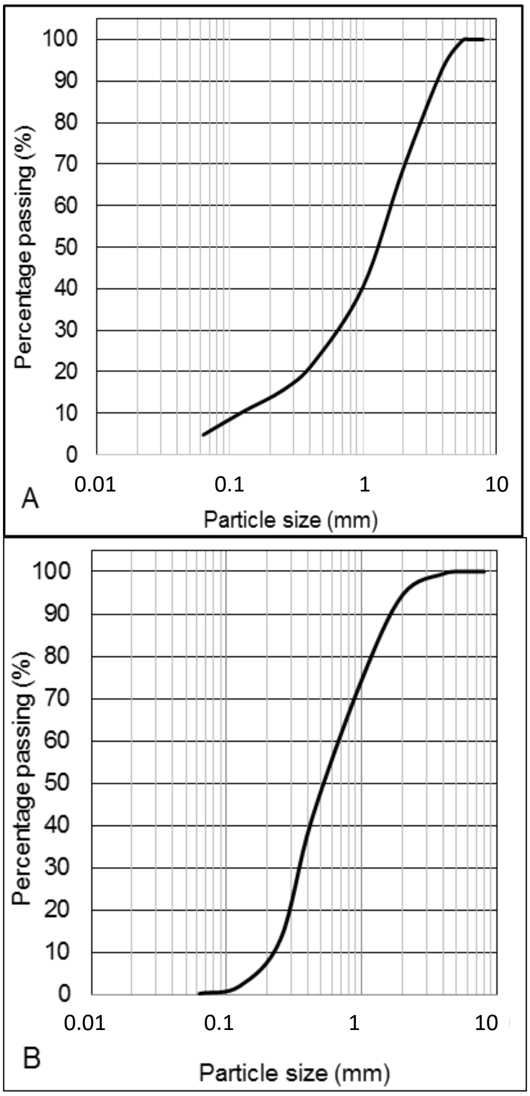

Fig. 3. Grain size distribution graphics of limestone (A) and silica sand (B) aggregates

3. Method

In this study, the effects of changes in the grain size distribution of fine aggregates on the physicomechanical behavior of building mortars were investigated. First of all, the grain size distributions of the two different aggregates were determined by sieve analysis following the EN 1015-1 standard. Subsequently, well-graded and uniform fine aggregate (<4000 µm) were prepared for both materials (limestone and silica sand aggregate) and mortars were prepared in accordance with EN 998-1 standard and their physicomechanical properties were determined. In order to compare the test results, each mixture was prepared in accordance with the standards, adhering to a fixed formula seen in Table 1, and the only variable was fine aggregate grain size and distribution characteristics.

Table 1. Mortar mixture proportions

Content	Percentage (%)
Fine aggregate (Fill material)	80
Cem I 42.5 cement	20
Water content	18

For this purpose, five well-graded fine aggregates with different maximum grain-size and uniform fine aggregates with various range of grain-size were prepared for each two type of aggregate. Thus, fine aggregates with 10 different particle sizes and range were composed for each material type. Special sieve apertures were used in the preparation of aggregates. Details of the particle size properties of the prepared fine aggregates are given in Table 2.

Six 160x40x40 mm prism-shaped hardened mortars for each aggregate mixture were prepared in accordance with EN 1015-11 standard. The tests of density, flexural and compressive strength, and thermal conductivity were carried out on the hardened mortar samples cured 28 days at 65C^0 (Fig. 4) in accordance with EN 1015-10, EN 1015-11 and EN 1745 standards, respectively. Thus, the effects of the particle size and grading change on the physicomechanical properties of the hardened mortar were analyzed.

Fig. 4. Mortar samples dried in the oven

Table 2. Special grain sizes and its codes prepared for the limestone ans silica sand

Sample No	C_1	C_2	C_3	C_4	C_5
	S_1	S_2	S_3	S_4	S_5
Grain Size (µm)	250	425	1000	2000	4000
Sample No	Cr_1	Cr_2	Cr_3	Cr_4	Cr_5
	Sr_1	Sr_2	Sr_3	Sr_4	Sr_5
Grain Size (µm)	125-250	250-425	425-1000	1000-2000	2000-4000

[**C:** Well-graded limestone fine aggregates with various maximum grain size from 250 µm (C_1) to 4000 µm (C_5), **Cr:** Uniform limestone fine aggregates with various grain size formed from the material remaining between two special sieves from 125-250 µm (C_{r1}) to 2000-4000 µm (C_{r5}), **S:** Well-graded silica sand limestone fine aggregates with various grain size formed from the material remaining between two special sieves from 125-250 µm (S_{r1}) to 2000-4000 µm (S_{r5}), **S_r:** Uniform silica fine aggregates with various grain size formed from the material remaining between two special sieves from 125-250 µm (S_{r1}) to 2000-4000 µm (S_{r5})]

3. Results and discussion

The grain size distribution curves obtained by sieve analysis show that both micronized fine aggregates are well-graded, in other words, they contain a balanced amount of each grain size (Fig. 3). As a result of physicomechanical experiments on 28-day prismatic hardened mortar samples prepared with uniform and well-graded special fine aggregate mixtures with different gradation produced from these well-graded aggregates, very remarkable results have emerged.

Average values of bulk density, compressional strength, flexural strength and thermal conductivity experiment results on hardened mortar samples are given in Table 3. The experimental results revealed that analysis on the basis of grading/uniformity, the grain size change and significantly affected the physicomechanical characteristics, as well.

Table 3. Physico-mechanical test results of the hardened mortars

Agg. type (origin)	Grading	Sample No	Bulk Density (Kg/m³)	Flexural Strength (N/mm²)	Compressive Strength (N/mm²)	Thermal Conductivity (W/m.K)
Limestone	Well-graded	C_1	1645	2.7	8.55	0.65
		C_2	1811	4.05	18.14	0.83
		C_3	1879	4.75	17	0.93
		C_4	1975	5.35	20.27	1.07
		C_5	2081	5.35	23.35	1.11
	Uniform	Cr_1	1652	2.35	6.55	0.66
		Cr_2	1679	2.7	9.35	0.69
		Cr_3	1600	3.9	11.9	0.61
		Cr_4	1849	2.55	7.03	0.89
		Cr_5	1769	2.08	9.05	0.79
Silica Sand	Well-graded	S_1	1589	2.4	7.4	0.6
		S_2	1732	2.7	9.07	0.75
		S_3	1806	3.25	12.4	0.82
		S_4	1881	3.8	13.17	0.94
		S_5	1916	4.35	13.9	0.99
	Uniform	Sr_1	1706	3.1	9.07	0.71
		Sr_2	1858	3.27	10.1	0.9
		Sr_3	1890	3.15	11.77	0.95
		Sr_4	1882	2.8	9.73	0.94
		Sr_5	1915	2.95	8.03	0.99

Bulk density of the mortar specimens increases meaningfully as the grain size of fine aggregate increases. The relationships between bulk density, and maximum and range of particle size in the fine aggregate (fill material) for the 28-day hardened mortar samples are shown in Fig 5-8. The correlation coefficient in the statistics was classified as strong, medium and weak for R≥0.8, 0.8<R<0.2 and R≤0.2, respectively (Smith, 1986). These graphs states that the increment of grain size amount increases the bulk density with strong correlations for both well-graded and uniform fine aggregates.

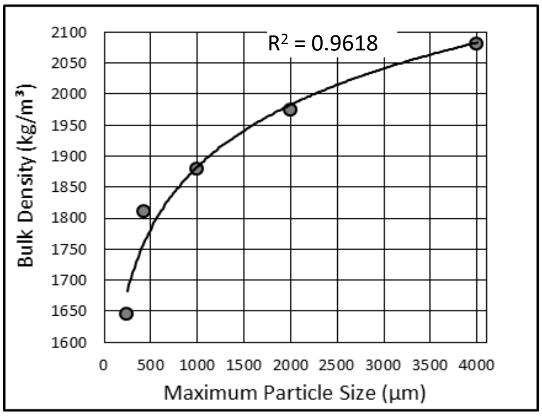

Fig. 5. Bulk density vs. max. particle size of well-graded limestone aggregate

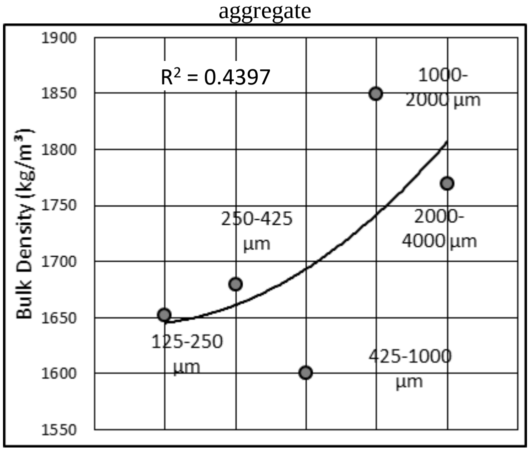

Fig. 6. Bulk density vs. particle size range of uniform limestone aggregate

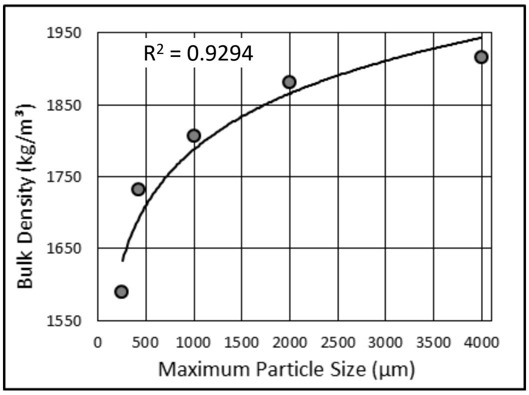

Fig. 7. Bulk density vs. max. particle size of well-graded silica sand aggregate

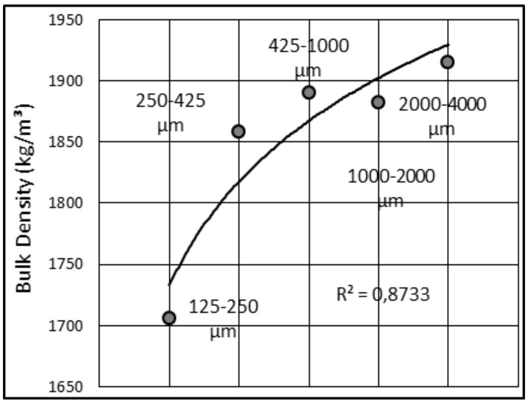

Fig. 8. Bulk density vs. particle size range of uniform silica sand aggregate

The strength test results show that both the compressional and flexural strength values of the 28-day hardened mortars including limestone fine aggregate are higher than those of the silica sand (Fig 8-11). On the other hand, irrespective of the aggregate type (origin), both the compressive and flexural strength of the mortars formed with well-graded fine aggregate for all grain-size category is particularly greater than of with uniform fine aggregate (Fig. 8 and 9).

The compressive and flexural strength of hardened mortars prepared using well-graded fine limestone aggregate increase exponentially with a high correlation coefficient as the grain-size increases (Fig. 9). On the other hand, both the compressional and flexural strength of mortars prepared with uniform fine limestone aggregate increases with increasing grain-size until a certain grain-size range, but after that maximum strength point at grain-size range between 425-1000 µm it decreases with increasing grain-size (Fig. 10). This situation indicates a bell curve model behavior.

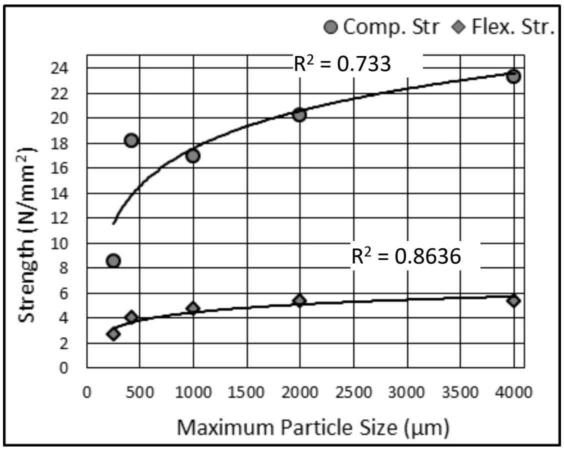

Fig. 9. Strength vs. max. particle size of well-graded limestone aggregate

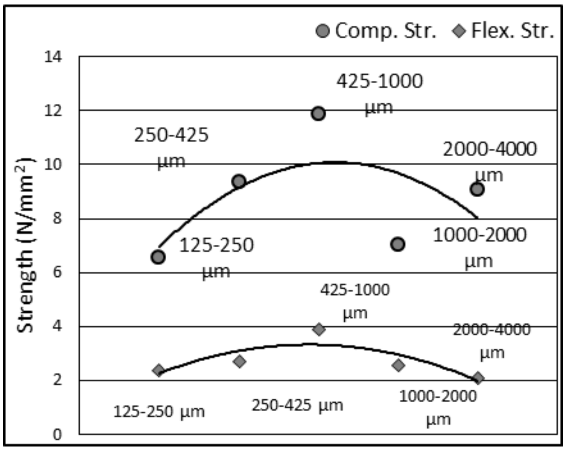

Fig. 10. Strength vs. particle size range of uniform limestone aggregate

A similar situation mentioned above is valid for the mortars prepared with fine silica sand aggregate (Fig 11 and 12), provided that they have lower strength values than those prepared with fine limestone aggregate. However, it is noteworthy that the correlations between both the compressive and flexural strength values of the mortars prepared with a well-graded fine silica-sand aggregate and the maximum grain-size are much stronger than those prepared with limestone. This means that the increase relationship in strength of the hardened mortars formed with well-graded fine silica-sand aggregate due to the maximum grain size increase has a much stronger correlation coefficient than those with limestone aggregate.

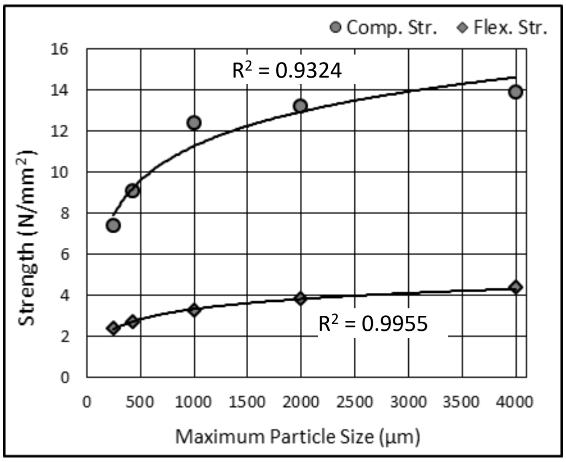

Fig. 11. Strength vs. max. particle size of well-graded silica sand aggregate

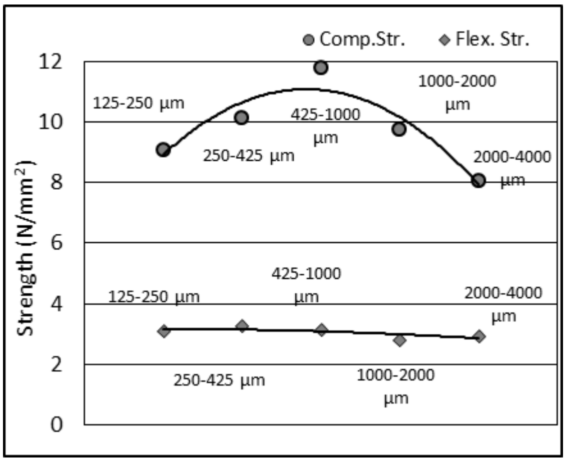

Fig. 12. Strength vs. particle size range of uniform silica sand aggregate

The thermal conductivity of the hardened mortars generally increases in proportion to the aggregate grain size increase. Especially, the relationship between thermal conductivity and maximum grain-size of well-graded fine aggregate for both limestone and silica-sand has a very strong positive correlation (Fig 13 and 15). The correlation coefficient of that relationship for the hardened mortars formed with uniform fine aggregates is strong, similar to those with well-graded and unlike medium (Fig. 14 and 16). Interestingly, the thermal conductivity value for the mortars formed with uniform fine limestone aggregate is minimum at the grain-size range of 425-1000 µm, where the strength is maximum, while the thermal conductivity for the mortars with uniform fine silica-sand aggregate has greatest values close together from this grain-size range. All of test results indicate that the grain-size range of 425-1000 µm for uniform fine aggregate is critical for strength and thermal conductivity.

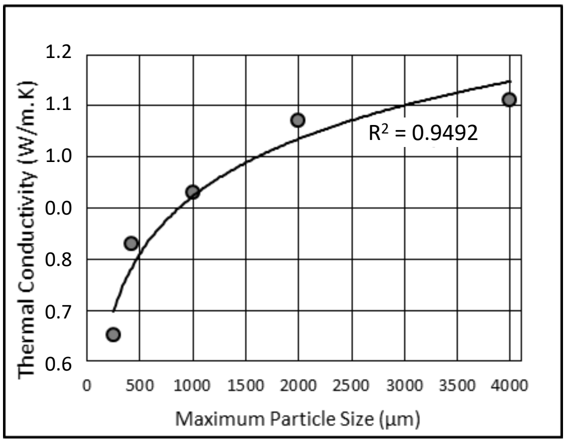

Fig. 13. Thermal conductivity vs. max. particle size of well-graded limestone aggregate

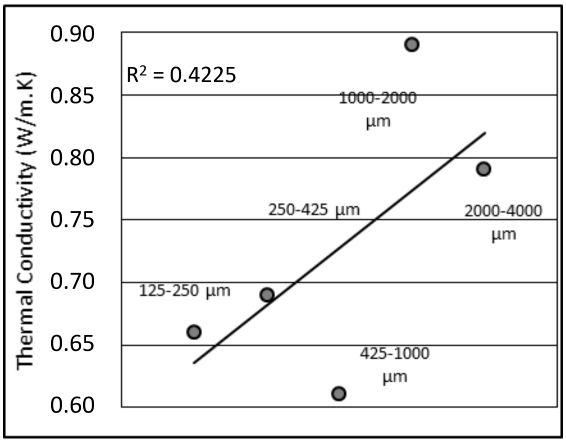

Fig. 14. Thermal conductivity vs. particle size range of uniform limestone aggregate

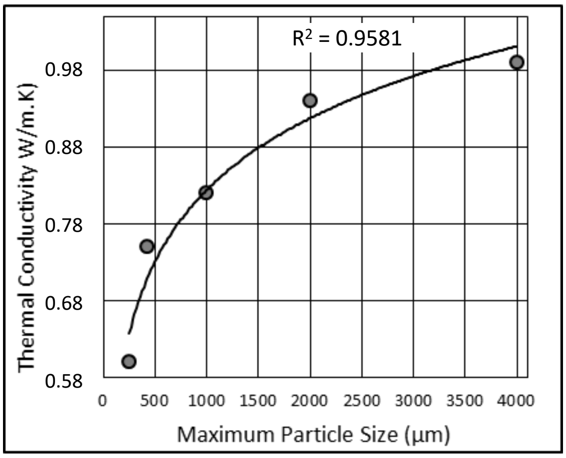

Fig. 15. Thermal conductivity vs. max. particle size of well-graded silica sand aggregate

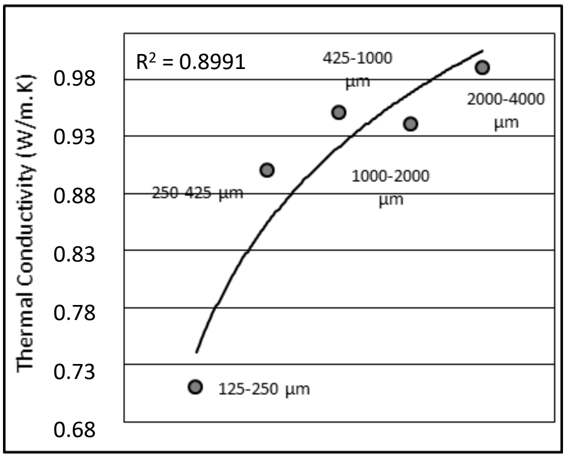

Fig. 16 Thermal conductivity vs. particle size range of uniform silica sand aggregate

4. Summary and conclusion

Numerous series of laboratory tests were performed to investigate the effect of a change of grain-size of well-graded and uniform fine aggregate on the physicomechanical characteristics such as bulk density, compressive and flexural strength, and thermal conductivity of 28-day hardened mortar. From the data and observations presented in this paper the following conclusions can be drawn:

- The increase in grain-size content of well-graded and uniform fine limestone and silica-sand aggregate increases the bulk density of hardened mortars.
- Both the compressional and flexural strength of hardened mortars including limestone fine aggregate is higher than that of the silica sand.
- Irrespective of the aggregate type (origin), both the compressive and flexural strength of the mortars formed with well-graded fine aggregate for all grain-size categories is particularly greater than of with uniform fine aggregate. This indicates that grading of fine aggregate make hardened mortars stronger, while uniformity decreases the strength.
- The compressive and flexural strength of hardened mortars prepared using well-graded fine aggregate increase exponentially with a high correlation coefficient as the grain-size increases.
- Regardless of the aggregate type, the compressional and flexural strength of mortars formed with uniform fine aggregate increases with increasing grain-size until the grain-size range of 425-1000 µm, but after this maximum strength point at that grain-size range it decreases with increasing grain-size.
- The thermal conductivity of the hardened mortars generally increases with the increase in the grain-size of aggregate. Especially, the relationship between thermal conductivity and maximum grain-size of well-graded fine aggregate for both limestone and silica-sand has a very strong positive correlation.
- The thermal conductivity value for mortars formed with uniform fine limestone aggregate is minimum at the grain-size range of 425-1000 µm, where the strength is maximum, while the thermal conductivity for the mortars with uniform fine silica-sand aggregate has greatest values close together from this grain-size range. All of test results indicate that the grain-size range of 425-1000 µm for uniform fine aggregate is critical for strength and thermal conductivity.

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細骨料的級配和粒度性質對建築砂漿的影響

關鍵詞
建築砂漿
細骨料
層次
強度
導熱係數

摘要
這項工作是關於細骨料性能對硬化砂漿物理力學特性的影響。結果表明，細骨料粒度的增加增加了硬化砂漿的堆積密度。包括石灰石細骨料在內的砂漿的強度高於矽砂。不論骨料來源如，對於所有粒度而言，具有良好梯度的細骨料的砂漿的強度均大於具有均勻細骨料的砂漿的強這表明細骨料的分級會增加強度，而均勻度則會降低強度。細骨料級配的砂漿的強度隨粒度的增加而增加。無論骨料的來源如何，具有均勻細骨料的砂漿的強度都會隨著粒度的增加而增加，直到粒度範圍為 425-1000 μm，但在此範圍之後，強度會隨著粒度的增加而降低。導熱率隨著晶粒尺寸的增加而增加。值得注意的是，良好分級的細骨料的導熱係數與最大晶粒尺寸之間的關係具有非常強的正相關性。另外，由均勻的細石灰石骨料形成的砂漿的熱導率值在 425-1000μm 的粒徑範圍內最小，而在該粒徑範圍內具有最大值。