EFFECTS OF SEPARATE AND INTERGRINDING ON SOME PROPERTIES OF PORTLAND COMPOSITE CEMENTS

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ABSTRACT

EFFECTS OF SEPARATE AND INTERGRINDING ON SOME PROPERTIES OF PORTLAND COMPOSITE CEMENTS

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In the production of cement, to increase the cement/clinker ratio and decrease CO_2 emission, the most important alternative is to produce mineral admixture incorporated cements (CEM II-III-IV-V) instead of portland cement (CEM I). These cements are usually produced by intergrinding the portland cement clinker and the mineral admixtures. However, the difference between grindabilities of the different components of such cements may cause significant effects on the particle size distribution and many other properties. For this reason, separate grinding of additives and clinker may be thought as an alternative. In this study, the effects of intergrinding and separate grinding on the particle size distribution and consequently on the strength of portland composite cements which contained natural pozzolan (trass), granulated blast furnace slag (GBFS) and limestone besides portland cement clinker were studied.

Keywords: Cement, portland composite cement, Ground Granulated Blast Furnace Slag, limestone, natural pozzolan (trass), separate grinding, intergrinding, particle size distribution, cement strength

ÖZ

AYRI VE BERABER ÖĞÜTMENİN PORTLAND KOMPOZE ÇİMENTOLARININ BAZI ÖZELLİKLERİ ÜZERİNE ETKİLERİ

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Çimento üretiminde çimento/klinker oranının arttırılması ve CO_2 emisyonunun azaltılması için en önemli alternatif, portland çimentosu (CEM I) yerine portland kompoze çimentolarının (CEM II-III-IV-V) üretilmesidir. Bu çimentolar genellikle portland çimento klinkeri ile mineral katkıların birlikte öğütülmesiyle üretilir. Fakat, bu çimentoların farklı bileşenlerinin öğütülebilirlikleri arasındaki fark, tane boyut dağılımını ve diğer birçok özelliğini kayda değer bir biçimde etkileyebilir. Bu amaçla katkıların ve klinkerin ayrı öğütülmesi alternatif bir yol olarak düşünülebilir. Bu çalışmada, portland çimento klinkerine ek olarak doğal puzolan (tras), granüle yüksek fırın curufu ve kireçtaşının ayrı ve beraber öğütülmesinin, tane boyut dağılımına ve dolaylı olarak dayanıma olan etkileri çalışılmıştır.

Anahtar Sözcükler: çimento, portland kompoze çimento, öğütülmüş granüle yüksek fırın curufu, kireçtaşı, doğal puzolan (tras), ayrı öğütme, beraber öğütme, tane boyut dağılımı, çimento dayanımı

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CHAPTER 1

INTRODUCTION

Cement is made by heating limestone, with small quantities of other materials (such as clay and iron ore) to 1450°C in a kiln, in a process known as calcination. Carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or lime, which is then blended with the other materials that have been included in the mix. The resulting material, called clinker, is then ground with a small amount of gypsum into a powder to make Ordinary Portland Cement.

When cement is batched and mixed with aggregate, water, chemical and mineral admixtures if necessary, in specified amounts, concrete is obtained. With an estimated annual consumption of 7.9 billion m^3 (U.S. Geological Survey, 2009), concrete is considered the most widely used construction material in the world. Cement is one of the main constituents of concrete and 2,8 billion tons of cement produced in 2007 all around the world (Kuleli, 2009).

The main steps of cement production are crushing, grinding, burning and final grinding operations. In the final grinding operation, which comes after the burning procedure, in order to produce portland cement, clinker must be ground in cement mills.

Grinding is the further size reduction step of clinker particles. Some of the important reasons for grinding are;

- separating one or more valuable minerals from the gangue components,
- increasing the specific surface area for specific chemical reaction,

- reducing the size of material to prepare it for the forthcoming process, and,
- providing market need about particle size specifications (Avşar, 2003).

In the cement industry there is no need for separating one or more valuable minerals from the gangue components. However, it is absolutely necessary to increase the specific surface area of raw material for further steps and providing market needs about particle size specifications in cement mills.

In the last step of producing portland cement, clinker is ground with approximately 3-5 % amount of gypsum. In portland composite cements, in accordance with specified standard, in addition to clinker, some materials such as granulated blast furnace slag (GBFS), natural pozzolans (trass), fly ash, or limestone are ground with the clinker. The cement/clinker ratio can be increased by using these additives so plants can produce more cement with less amount of clinker. It is obvious that using less clinker is good for plant not only for economic but also environmental reasons. Therefore, cement additives are commonly used in the cement industry especially in clinker grinding. CEM (II-III-IV-V) types comprise 60 percent of the total cement sales in 2008 according to statistics of Turkish Cement Manufacturers' Association. (58 percent in 2007 and 57 percent in 2006).

In the production of portland composite cements there are two alternatives for grinding clinker and additives: intergrinding and separate grinding. A new and more preferable method, especially in GBFS-additive cement production, is to grind clinker and GBFS separately and then mix them according to product which has been used (Öner, 2000). It is obvious that there are some advantages and disadvantages of these grinding methods for cement plants.

1.1 OBJECTIVE AND SCOPE

The objective of this study is to compare various effects of two different grinding methods which are intergrinding and separate grinding of additives and clinker on the properties of Portland composite cements. The positive and negative effects of these two grinding methods which can be used in the cement industry may help cement plants to produce cements with mineral additives and to understand the behavior of such cements in mortars and concrete. In the production of cement, increasing the cement/clinker ratio and using less clinker decrease CO_2 emission. The most important way is to produce blended cements (CEM II-III-IV-V) instead of portland cement (CEM I). With the addition of some acceptable mineral materials instead of clinker, plants can produce portland composite cements. It is certain that these products must be suitable for the market demands.

In the production of CEM II-B type of cements the additive material amount must be between 21-35 %. Clinker and other materials are usually ground together in the industry. However, it is thought that the difference between the grindabilities of mineral additives and clinker may cause significant changes on the particle size distribution of cement and the resulting concrete properties. For this reason, separate grinding of the materials may be thought of as an alternative. In this study, the effects of intergrinding and separate grinding on various properties of CEM II cements were studied.

It was planned to find the differences between the separate grinding and intergrinding methods in terms of grinding time and other product properties. These grinding methods affect the cement characteristics by resulting in changes in the particle size distribution. Consequently, the strength development is affected by these changes. In addition, the effects of intergrinding and separate grinding were compared according to TS-EN 196 and ASTM C109.

CHAPTER 2

LITERATURE REVIEW

In the production of the portland composite cement, intergrinding and separate grinding of clinker with additives were investigated in terms of grindability, particle size distribution and strength development. The most common knowledge about this type of study is that intergrinding additives with clinker is less energy-demanding than separate grinding, especially for the production of high-fineness products (Tsivilis et al., 1991).

In the intergrinding process, some special characteristics of additives can affect the clinker characteristics in terms of particle size distribution and also the strength development.

In the study of Turanlı et al. (2004), characteristics of 55% trass (by weight) containing cement were investigated in terms of particle size distribution, heat of hydration, water demand, setting time, and compressive strength. As a result they found that the particle size distribution of clinker was highly affected by the hardness of the trass. Harder trass can cause finer ground clinker, whereas softer trass results coarser ground clinker. Another important result was that the strength of cement was affected not only by the pozzolanic activity of trass and the chemical composition of the clinker, but also by the particle size distribution of cement which was produced with intergrinding of the materials.

Erdoğdu et al. (1999) conducted a similar study with trass and granulated blast furnace slag as additives. One of their conclusions was about the material interaction during the intergrinding, similar to other studies. In intergrinding, different materials do not show the same behavior as in the case of separate grinding. Therefore, it was concluded that during intergrinding some interactions occur between the particles of different ingredients of blended cements. These interactions can easily be seen in the higher particle size ranges relative to the small particle sizes. The other conclusion was that the interground cement can be finer than the separately ground one upon a slight increase in the grinding time. This result is independent from the hardness of the materials.

In another study about grindabilities of clinker and trass mixtures by Hoşten and Avşar (1998)**,** it was shown that after Bond test of the cement, which was produced by intergrinding with trass, some interactions occur between the particles of clinker and trass. These interactions cause the difference in particle size distribution and the consequent strength development.

Binici et al. (2007) studied the effect of particle size distribution on the properties of cements incorporating ground granulated blastfurnace slag and natural pozzolan. They concluded that the separately ground cements were finer than the interground cements and also these cements had higher compressive strength. In screening, the separately ground specimens had higher passing percentage for every screen size relative to the interground cements.

In a study by Li et al. (2002), there was also the same idea about advantage of separate grinding. They claimed that separate grinding can easily be adapted to the production of composite cements containing GBFS and fly ash. Moreover, by using calcined gypsum and suitable activators, it is possible to produce high-strength composite cements with large amount of admixture materials such as GBFS, limestone and fly ash.

2.1 PORTLAND CEMENT

According to EN 197-1 “Cement is a hydraulic binder, i.e., a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes and which, after hardening, retains its strength and stability even under water.”

2.2 CEMENT ADDITIVES

2.2.1 Natural Pozzolan (Trass)

Natural pozzolans are defined as either raw or calcined natural materials that have pozzolanic properties (e.g., volcanic ash or pumicite, opaline chert and shales, tuffs, and some diatomaceous earths). Historically, they are among the oldest materials used in combination with lime for construction purposes. In modern construction technology, natural pozzolans are still used in various applications. They are used either as admixtures for concrete or as a blended component in the production of portland–pozzolan cements. It is generally accepted that the use of natural pozzolans in cement or concrete systems results in many beneficial properties such as low heat of hydration, high ultimate strength, low permeability, high sulfate resistance, and low alkali–silica activity (ACI Report, 1994). In addition, it is known that the use of pozzolanic and cementitious materials in large quantities is very important regarding the sustainability of the cement and concrete industry. This importance is not only related to the energy efficiency and environmental aspects of cement industry but also with the durability and life cycle cost of concrete structures (Mehta, 1998).

2.2.2 Ground Granulated Blast Furnace Slag (GGBFS)

Blast furnace slag, more particularly in granulated form, is so-called latently hydraulic material, i.e. it needs an activator to enable it to harden “hydraulically”. In practice, calcium hydroxide (in cement clinker or hydrated lime) and sulphates (gypsum, anhydrite) are used as activators. Slowly cooled, crystalline blast furnace slag in lump form is unsuitable, however; to possess latent hydraulicity by quenching the molten slag in water yields a granulated product. The granulated blast furnace slag should have the lowest possible residual water content (favorable values are below 10 %). The particle size is usually below 3 mm.

The hydraulic properties of blast furnace slag are determined by its chemical composition and its glass content. The latter should be above 90 %. Methods of producing slag with 95-100 % glass content are now available.

The chemical composition of granulated blast furnace slag used in cement manufacture is approximately in the range indicated in Table 2.1.

Table 2.1: Chemical compositions of the granulated blast furnace slags used in cement manufacture (% by weight)

OXIDE	**CONTENT**
CaO	35-48
SiO_2	28-38
Al_2O_3	9-18
MgO	2-10
S	1-3
FeO	0-2
MnO	0-2
Na_2O	0-2

A more reliable method of determining the hydraulic properties of a granulated blast furnace slag consists of intergrinding it with clinker and gypsum to produce a slag cement with a high slag content (in the laboratory) and testing this cement for strength and, if necessary, for other properties as well. For comparison, a “cement” may be made which contains, instead of slag, an equal quantity of an inert substance (e.g., quartz sand) of the same fineness or, alternatively, a portland cement made from the same clinker, but without slag, may be ground to the same fineness as the slag cement and tested (Labahn, 1983).

2.2.3 Limestone

Limestone is a sedimentary rock composed largely of the mineral calcite (calcium carbonate $CaCO_3$). The deposition of limestone strata is often a by-product and indicator of biological activity in the geologic record. Limestone is a key ingredient of quicklime, mortar, cement, and concrete. Limestones, when ground sufficiently fine and suitably incorporated into cements can be used to lower the water demand by improving the overall particle grading. In the case of 28-day-strength, their presence is essentially that of a diluent, but early strengths may improve relative to those achieved with pozzolans. Calcium carbonate has also been reported to react with the tricalcium aluminate to form high and low forms of the carboaluminate supporting other evidence that small amounts of limestone can act as partial substitutes for gypsum (Hewlett, 2004).

CHAPTER 3

EXPERIMENTAL STUDY

3.1 MATERIALS

Trass, GBFS and limestone were used as mineral admixtures. These materials were ground with clinker and a small amount of gypsum in some proportions. The amount of mineral addition was 20-40 % and there were 18 different combinations of these additives. In each cement produced, gypsum amount was taken 5% of the clinker amount. The oxide compositions of the clinker and mineral admixtures used are given in Table 3.1.

The cements produced were designated by some numbers and letters. Numbers indicate the proportions of the materials in the mixture and letters are the first letter of the mineral admixtures.

For example, 80T10S10 means %80 clinker with 10% trass and 10% slag.

Proportions of the constituents and the designations used for the cements produced are given in Table 3.2.

In some samples only one additive was used and maximum two different additives were used in these combinations. In all of the grinding steps, grinding media was prepared as ~ 3 kg for small scale laboratory mills.

Table 3.1: The oxide compositions and other properties of clinker and mineral admixtures

	CLINKER	**TRASS**	**LIMESTONE**	**GBFS**	**GYPSUM**
CaO	64.29	2.84	48.42	33.37	33.69
SiO_2	21.23	66.54	6.90	39.56	1.08
Al_2O_3	5.26	16.35	2.01	15.84	0.37
Fe_2O_3	3.85	3.57	0.63	0.73	0.10
MgO	2.07	0.69	1.13	6.13	0.23
SO_3	1.20	0.09	0.10	0.24	42.79
K_2O	0.81	3.11	0.52	1.05	0.03
Na_2O	0.11	4.48	0.03	0.46	0.05
Cr_2O_3		0.03	0.00	0.04	0.01
Loss on Ignition	0.44	2.11	39.55	0.00	20.82
TOTAL	**99.25**	**99,81**	**99.29**	**97.44**	**99.17**
Free-lime	0.70				
Lime Saturation Factor	0.95				
Silica module	2.33				
Alumina module	1.37				
C2S	18.15				
C3S	56.64				
C3A	7.43				
C4AF	11.72				
Crystal water content					20.26

Table 3.2: Cements used in the experimental study

Code	% Clinker	% Trass (T)	% Limestone (L)	% GBFS (S)	% Gypsum	% Total
100 C	100	0	0	0	5.0	105.0
80T20	80	20	0	0	4.0	104.0
80T10L10	80	10	10	0	4.0	104.0
80T10S10	80	10	0	10	4.0	104.0
80L20	80	0	20	0	4.0	104.0
80L10S10	80	0	10	10	4.0	104.0
80S20	80	0	0	20	4.0	104.0
70T30	70	30	0	0	3.5	103.5
70T15L15	70	15	15	0	3.5	103.5
70T15S15	70	15	0	15	3.5	103.5
70L30	70	0	30	0	3.5	103.5
70L15S15	70	0	15	15	3.5	103.5
70S30	70	0	0	30	3.5	103.5
60T40	60	40	0	0	3.0	103.0
60T20L20	60	20	20	0	3.0	103.0
60T20S20	60	20	0	20	3.0	103.0
60L40	60	0	40	0	3.0	103.0
60L20S20	60	0	20	20	3.0	103.0
60S40	60	0	0	40	3.0	103.0

3.2 EXPERIMENTAL METHODS

After sampling the materials from the plant site, experiments started at the quality control laboratory. Having removed the moisture of material in the oven, first size reduction step was started at first crusher (jaw crusher type).

Then, the crushed material was put into the oven at ~ 105 °C again and the second size reduction step was started by using the second crusher (jaw crusher type but smaller close and open size setting than the first crusher). Before the second crushing step, materials were weighed and mixed as stated in Table 3.2 in the intergrinding steps. In the separate grinding, all of the materials were crushed and ground alone as 3000 g and after grinding, they were mixed as the stated proportions.

There were two types of grinding mills used in the experiments. In the intergrinding steps and only clinker grinding steps of the separate grinding, one mill (cement mill) was used. The other mill (additive mill) was used for trass, limestone, GBFS and gypsum grinding. Both of the mills have 300 mm outer / 255 mm inner length and 275 mm outer / 250 mm inner diameter. Size distribution of the balls were nearly same as the industrial mills of the SET Ankara Cement Plant. Size and weight information of the ball/cylpeps are shown in Tables 3.3 and 3.4.

Table 3.3: Size and weights of the ball/cylpeps (cement mill)

Ball Diameter /cylpeps length (mm)	Ball/cylpeps weight(kg)
50	2.5
30	2.0
20	2.0
25	1.0
22	4.0
16	14.0

Table 3.4: Size and weights of the balls (additive mill)

Ball Diameter (mm)	Ball Weight (kg)
80	2.10
70	2.80
60	2.68
50	4.10
30	5.65
20	6.95

As the specific surface area of all the samples was aimed as 3500±200 cm^2/g (Blaine), the duration of the grinding was adjusted to reach this target. The Blaine test was done according to TS-EN 196-6 after some grinding and if the Blaine value was smaller than ~ 3300 cm^2/g, further grinding was done.

Density of the raw and mixing materials was calculated with a pycnometer before all of the Blaine measurements. Upon reaching the desired Blaine value, the material was taken from the mill and screened with the 1000 μm (18 mesh) screen. All of the oversize residues were removed from the samples for consistency of the experiments (less than 1% amount). In the intergrinding step of the experiments screened material was directly packaged for the further steps. However, in the separate grinding, materials were mixed in the given proportions and then a final Blaine determination test was applied for all the separately-ground samples before packaging.

Laser granulometry tests (dry analysis) for all of the samples (interground and separately ground) and raw materials were done after taking ~ 25 g specimens from the 3 kg samples.

Chemical analysis of cement samples and raw materials were done in XRF according to TS-EN 196-2. Each cement type prepared in two different grinding methods had nearly the same chemical compositions. Moreover, chemical proportions of all cements were between the limit values of required standards. Chemical analysis of cement samples is given in Appendix B.

After all of the samples were prepared, their mortar tests were started. For compressive strength determination, molds were prepared according to TS-EN 196-1. All of the tests done for the strength determination were repeated according to ASTM C 109. Flow table was used in this part of the test and 110±10 % of flow was accepted in this part of the experiment.

Cement pastes were prepared according to TS-EN 196-3 in order to determine setting time and soundness.

All of the experiments were done in the laboratory of SET Ankara Cement Plant. Brands and models of the machines were given in Table 3.5.

Table 3.5: Brands and models of the machines in the laboratory

Machine	**Trademark-brand**	**Year**
Oven	Şimşek Laborteknik	2007
II. Crusher	Retsch BB1	2000
Pycnometer	Micromeritics, Accu Pyc II 1340	2008
Blaine	Atom Teknik	2007
Laser granulometry	Malvern MS 2000	2003
X-ray analyzer (XRF)	Thermo Electon SA ARL 9900	2008
Mortar mixer	Atom Teknik	2004
Jolting Table	Atom Teknik	2008
Comp. Strength Test	Atom Teknik	2007
Vicat Test	Toni Technik Otomatic Vicat	2007

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GRINDING TIMES AND BLAINE ANALYSIS

The cements prepared in this investigation are double and triple blends, except the control cement which consists of only portland cement clinker. The three mineral admixtures were first used to replace 20, 30 and 40% (by weight) of the clinker portion and then for each replacement level half of the admixture used was replaced by a second mineral admixture. Since the grindabilities of the individual ingredients were different from each other, same cement types were prepared by both intergrinding and separate grinding. All cements were tried to be kept at a constant Blaine fineness of 3500±200 cm^2/g.

Thus, there are nine double blend and nine triple blend cements prepared by both intergrinding and separate grinding, resulting in 18 different blended cements and 36 different cement samples. Their strength properties were investigated for constant water-cement ratio as described in TS EN 196 and for a constant workability of 110±10% flow as stated in ASTM C 109.

Grinding time, density and Blaine value of the interground samples were given in Table 4.1.

Table 4.1: Final Blaine and total grinding times of interground samples

Code	d (g/cm^3)	Grinding time (min.)	Blaine (cm^2/g)	Additional grinding (min.)	Blaine (cm^2/g)	**Total grinding time (min.)**	**Final blaine (cm^2/g)**
100 C	3.19	130	3585			**130**	**3585**
80T20	3.04	90	3044	10+3+2	3242/3324/3465	**105**	**3465**
80T10L10	3.04	75	3192	5	3451	**80**	**3451**
80T10S10	3.10	120	3355	5	3440	**125**	**3440**
80L20	3.07	90	3611			**90**	**3611**
80L10S10	3.13	105	3540			**105**	**3540**
80S20	3.11	100	2936	15+20+5	2996/3322/3520	**140**	**3520**
70T30	2.96	90	3474			**90**	**3474**
70T15L15	2.98	65	3610			**65**	**3610**
70T15S15	3.05	100	3082	10	3383	**110**	**3383**
70L30	3.01	65	3690			**65**	**3690**
70L15S15	3.08	90	3510			**90**	**3510**
70S30	3.08	120	3022	15+5+10	3300/3345/3488	**150**	**3488**
60T40	2.87	73	3106	10+2+12	3365	**97**	**3365**
60T20L20	2.93	65	3621			**65**	**3621**
60T20S20	2.99	95	2975	10+15+5	3070/3249/3336	**125**	**3336**
60L40	2.96	40	3382			**40**	**3382**
60L20S20	3.04	75	3145	15	3628	**90**	**3628**
60S40	3.05	155	3325	8	3418	**163**	**3418**

The difference of the grindabilities of the materials can be easily seen from Table 4.1. When considering the total grinding time, it can be concluded that limestone was easy to grind. Grinding of trass was more difficult than the limestone, and slag grinding was the most difficult. This result can be extracted from the Table 4.2 which was prepared for separately ground samples.

Table 4.2: Final Blaine and total grinding times of separately ground samples

Material	d (g/cm^3)	Grinding time (min.)	Blaine (cm^2/g)	Additional grinding (min.)	Blaine (cm^2/g)	**Total time (min.)**	**Final blaine (cm^2/g)**
Clinker 1	3.26	120	2801	15+5	3274/**3337**	**140**	**3337**
Clinker 2		135	3124	15+10	3261/**3481**	**155**	**3481**
Clinker 3		150	3264	10	**3428**	**160**	**3428**
Clinker 4		160	**3315**			**160**	**3315**
Clinker 5		165	**3355**			**165**	**3355**
Clinker 6		165	**3448**			**165**	**3448**
Clinker 7		165	**3339**			**165**	**3339**
Clinker 8		170	**3337**			**170**	**3337**
Clinker 9		165	**3396**			**165**	**3396**
Clinker 10		165	**3364**			**165**	**3364**
Clinker 11		160	**3289**			**160**	**3289**
Clinker 12		170	**3434**			**170**	**3434**
Clinker 13		170	**3493**			**170**	**3493**
Limestone 1	2.71	25	**3494**			**25**	**3494**
Limestone 2		25	**3319**			**25**	**3319**
Trass 1	2.52	45	2084	25+23+ 13	2650/3267/**3621**	**106**	**3621**
Trass 2		100	**3493**			**100**	**3493**
Slag 1	2.88	180	2394	75+60+ 15	2964/3335/**3445**	**330**	**3445**
Slag 2		300	3058	35	3271/**3436**	**335**	**3436**
Gypsum 1	2.34	20	2312	15+25+10+10	2727/3224/3244/**3582**	**80**	**3582**

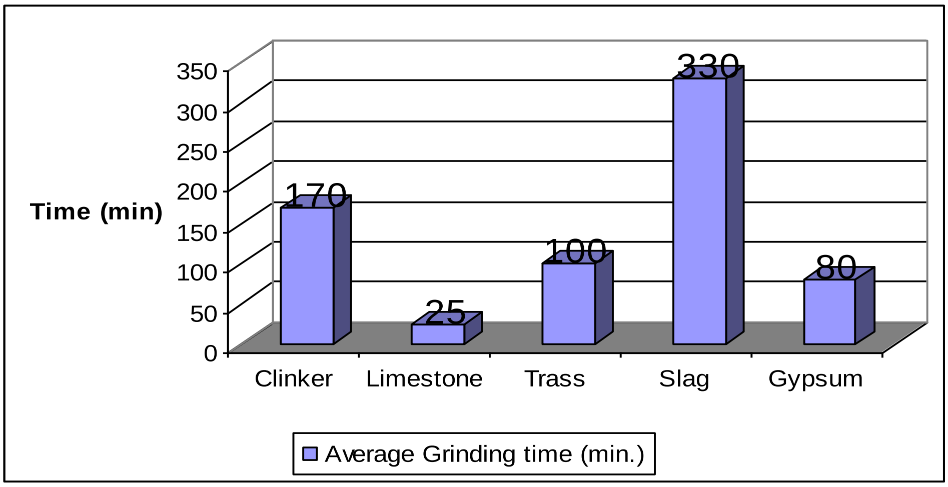

Figure 4.1: Average grinding times for each material to reach ~ 3500 cm^2/g.

In separate grinding, all of the materials were ground separately and the grinding times, which were stated above, can give an idea about their grindabilities. The psd of the raw materials can be seen in Figure 4.2.

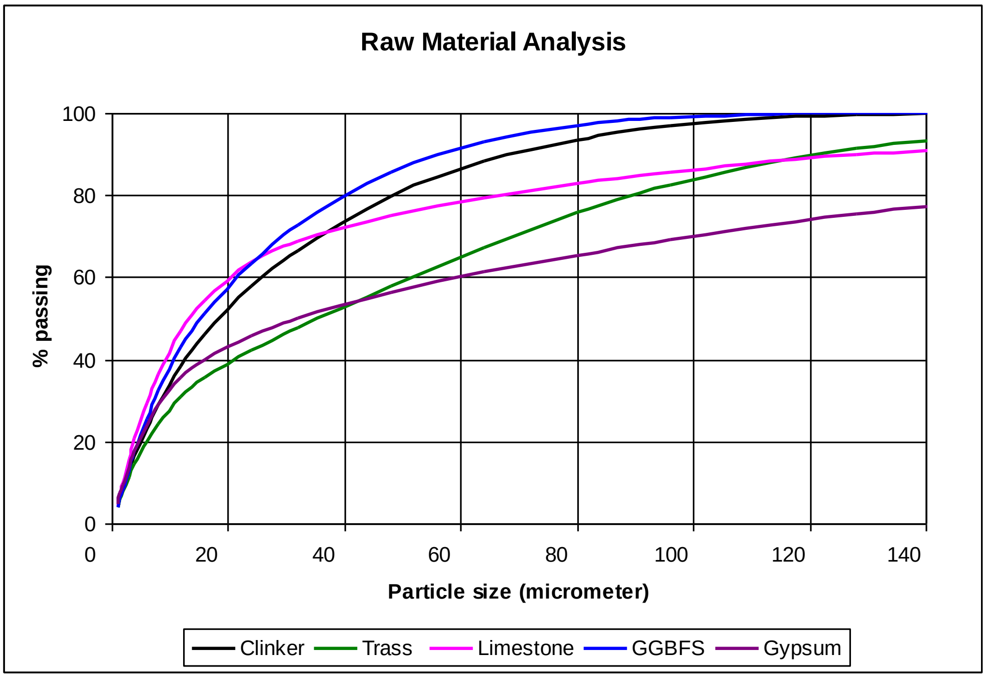

Figure 4.2: Particle size analysis of the raw materials of nominally the same Blaine fineness

It can be seen that the clinker and GGBFS have finer particles relative to the other materials. Although, gypsum has 3582 cm^2/g Blaine value, it has some coarse particles in it. Similar to gypsum, trass and limestone have also some coarse particles.

For comparative purposes, Blaine values of the separately ground samples must be similar to those of the interground ones. The procedure of mixing the separately ground materials in given proportions was very important to reach these values. The Blaine fineness tests for each sample after blending were done and these values were approximately 3500 cm2/g.

Table 4.3: Final Blaine of interground and separately ground materials

Sample	**Blaine cm^2/g (Interground)**	**Blaine cm^2/g (Separately ground)**
80T20	3465	3402
80T10L10	3451	3290
80T10S10	3440	3303
80L20	3611	3494
80L10S10	3540	3453
80S20	3520	3321
70T30	3474	3424
70T15L15	3610	3429
70T15S15	3383	3314
70L30	3690	3407
70L15S15	3510	3420
70S30	3488	3313
60T40	3365	3251
60T20L20	3621	3417
60T20S20	3336	3300
60L40	3382	3290
60L20S20	3628	3502
60S40	3418	3359
MINIMUM	**3336**	**3251**
MAXIMUM	**3690**	**3502**

4.2 PARTICLE SIZE ANALYSIS

4.2.1 Comparison of Portland-Pozzolan (Trass), Portland-Limestone and Portland-GGBFS (Slag) Cements

In order to analyze the strength of portland composite cements and to understand the interaction between the different mineral admixtures used, a comparison of double blend cements is necessary first.

4.2.1.1 Particle Size Distributions of Portland-Pozzolan (Trass) Cements

The particle size distributions (psd) of trass incorporated cements are given in Figures 4.3 and 4.4, for intergrinding and separate grinding, respectively. Comparison of these two figures indicates that although the Blaine fineness values of the cements are approximately the same their psd's are different. Since the trass is softer than the clinker, besides the standard mill charge, the clinker must have a further grinding effect on the trass. Therefore, the finer portion of the interground Portland-pozzolan (trass) cements should contain more trass and the clinker portion remains coarser in comparison with the control cements. This, besides the reduction in the clinker portion by trass replacement, may have further effects on the strength. On the other hand, in separate grinding, the psd of each ingredient remains unaffected by the other. Therefore, the sole effect of the trass content can be separately determined.

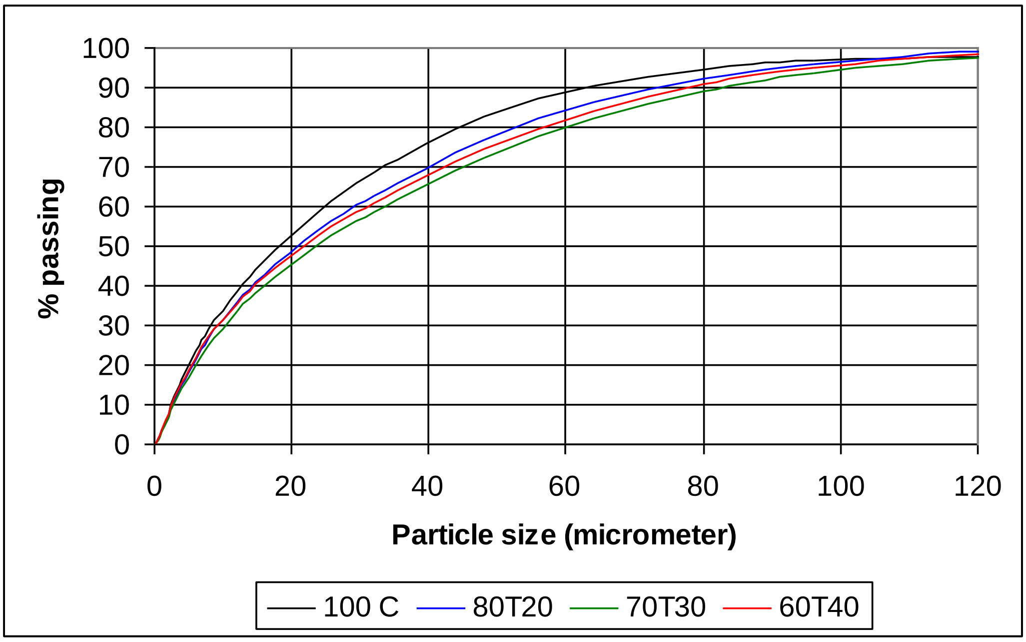

Figure 4.3: Particle size distribution of portland-pozzolan (trass) cements (interground).

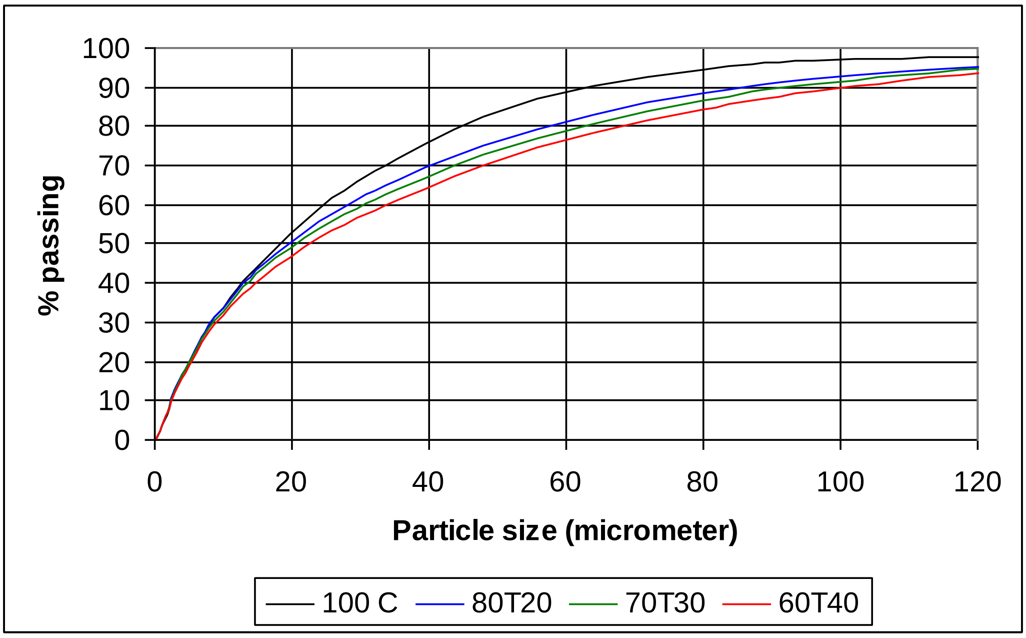

Figure 4.4: Particle size distribution of portland-pozzolan (trass) cements (separately ground).

4.2.1.2 Particle Size Distributions of Portland-Limestone Cements

The psd's of limestone incorporated cements are given in Figures 4.5 and 4.6, for intergrinding and separate grinding, respectively. A very similar discussion to that made for natural pozzolan (trass) incorporated cements holds true for limestone incorporated cements. Besides, limestone being much softer, results in a coarser clinker portion upon intergrinding. Considering the amount of material finer than 60 μm, for example, for 40 % limestone incorporation, the value is 70 % upon intergrinding whereas it is 75 % upon separate grinding. This shows that intergrinding shifts the psd to the coarser side.

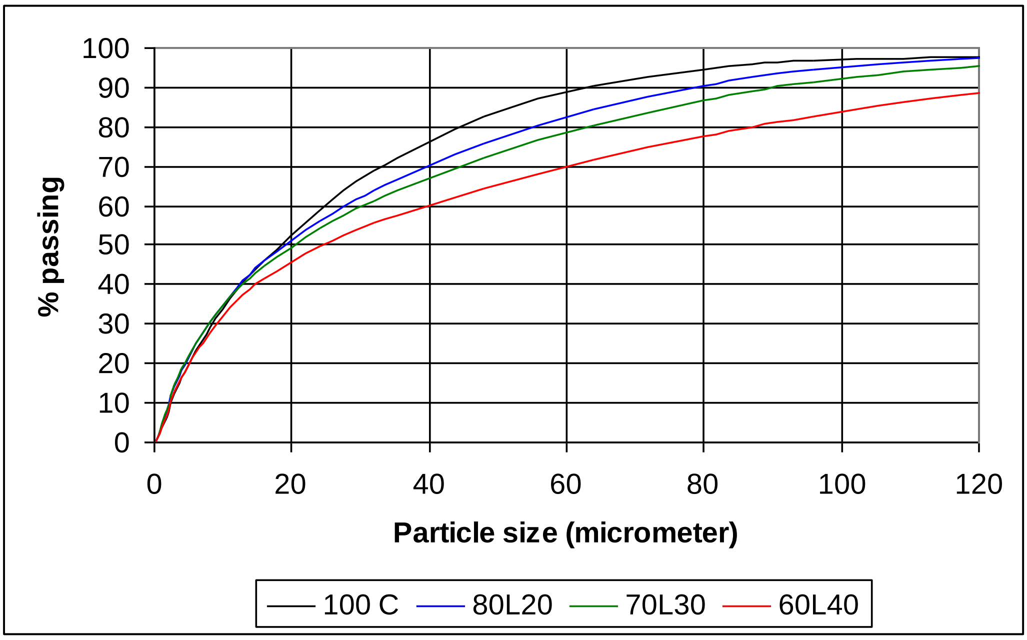

Figure 4.5: Particle size distribution of portland-limestone cements (interground).

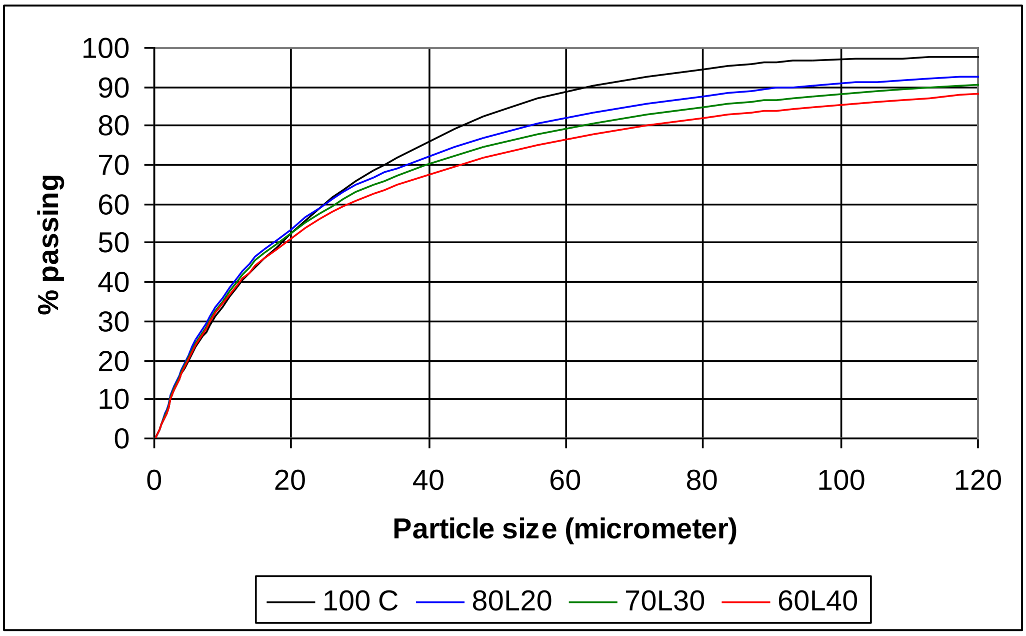

Figure 4.6: Particle size distribution of portland-limestone cements (separately ground).

4.2.1.3 Particle Size Distributions of Portland-GGBFS Cements

The psd's of GGBFS incorporated cements are given in Figures 4.7 and 4.8, for intergrinding and separate grinding, respectively. Unlike the first two cases, GGBFS incorporation does not shift the psd to the coarser side. On the contrary, it shifts the psd to the finer side slightly.

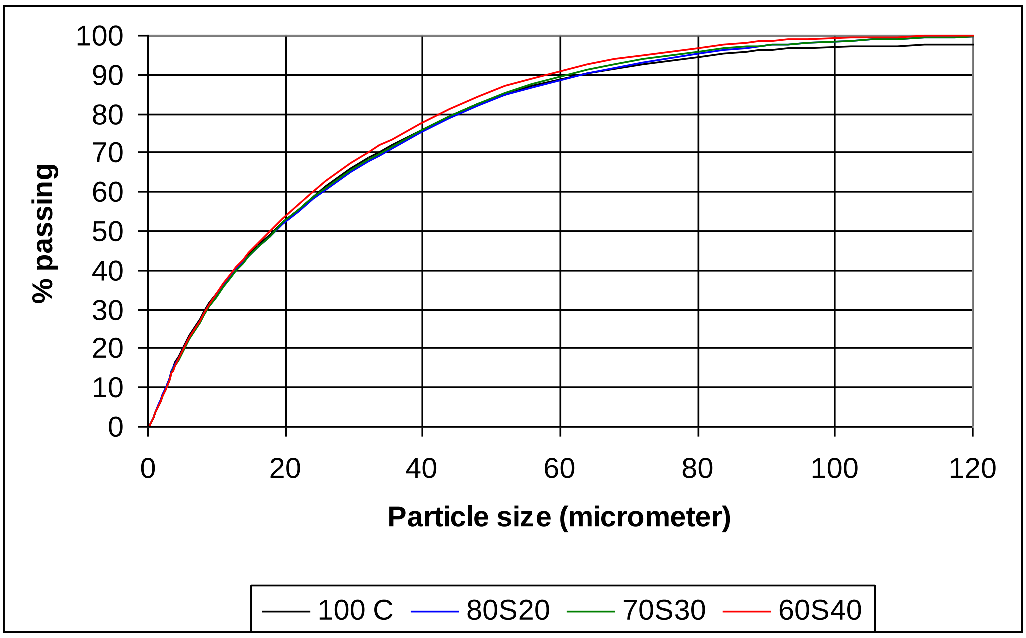

Figure 4.7: Particle size distribution of portland-GGBFS cements (interground).

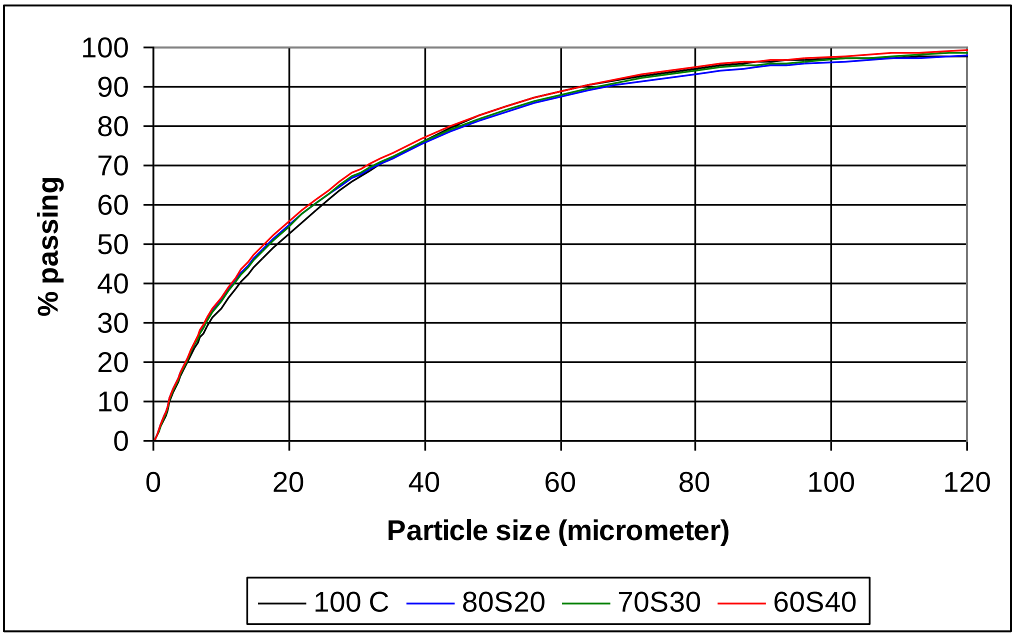

Figure 4.8: Particle size distribution of portland-GGBFS cements (separately ground).

The particle size distributions of both interground and separately ground GGBFS incorporated cements are almost the same as that of the control cement. Since the GBFS is much harder than the clinker, besides the standard mill charge, the GBFS must have a further grinding effect on the clinker. Therefore the finer portion of the interground Portland-GGBFS cements should contain more clinker. It can be observed that in intergrinding, the clinker portion becomes finer if the additive is harder than clinker (slag) as in the study of Turanlı et al. (2004). On the other hand, clinker will be coarser if the additive is softer (limestone and trass). Although the clinker portions of the GGBFS incorporated cements are reduced their reactivity may have been improved due to increased fineness. Again considering the amount of material finer than 60μm, for example, for 40% GBFS incorporation, the value is 90% upon intergrinding whereas it is 88% upon separate grinding. This shows that separate grinding shifts the psd slightly to the coarser side. On the other hand, in separate grinding, the psd of each ingredient remains unaffected by the other. Therefore the sole effect of the GBFS content can be separately determined.

4.2.2 Particle Size Distributions of Triple Blends (Interground)

The effect of incorporating a third component by replacing half of the mineral admixture used on the particle size distribution and strength were also studied.

4.2.2.1 Natural Pozzolan (Trass) Replacement by Limestone or GGBFS in Interground Cements

The psd's of the interground triple blends in which half of the natural pozzolan (trass) is replaced by either limestone or GGBFS are given in Figure 4.9-10 and 11 for 20, 30 and 40 % clinker replacement levels. It can be observed from these figures that if the third component in the blend is harder (GGBFS) than the other two (clinker and natural pozzolan), the psd shifts to the finer side relative to the first case's particle size distribution. On the other hand, if the third component is softer (limestone), the resulting cement will have a coarser particle size distribution.

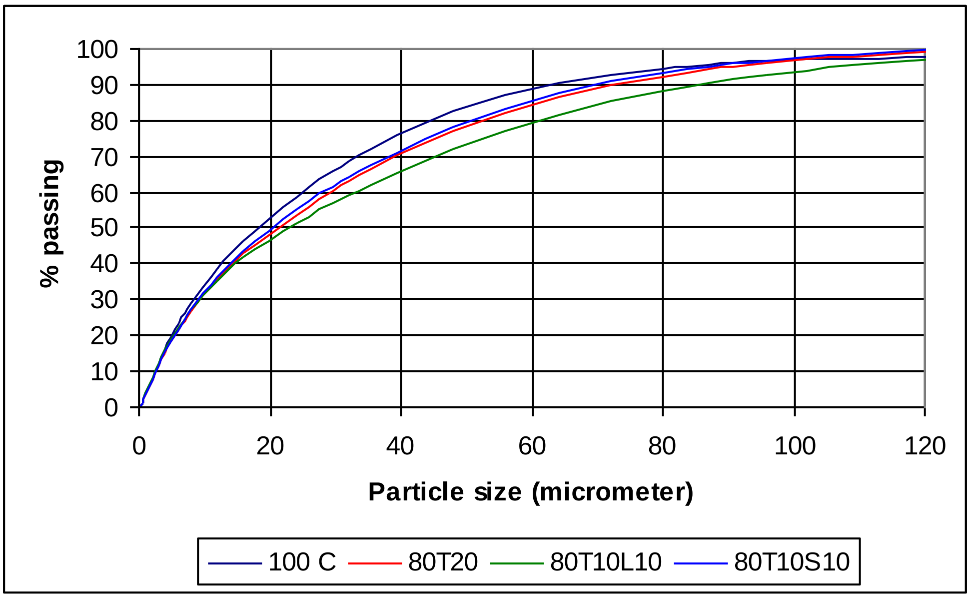

Figure 4.9: Particle size distributions of 20% mineral admixture incorporated interground triple blends. Limestone and GGBFS replaced half of the natural pozzolan (trass).

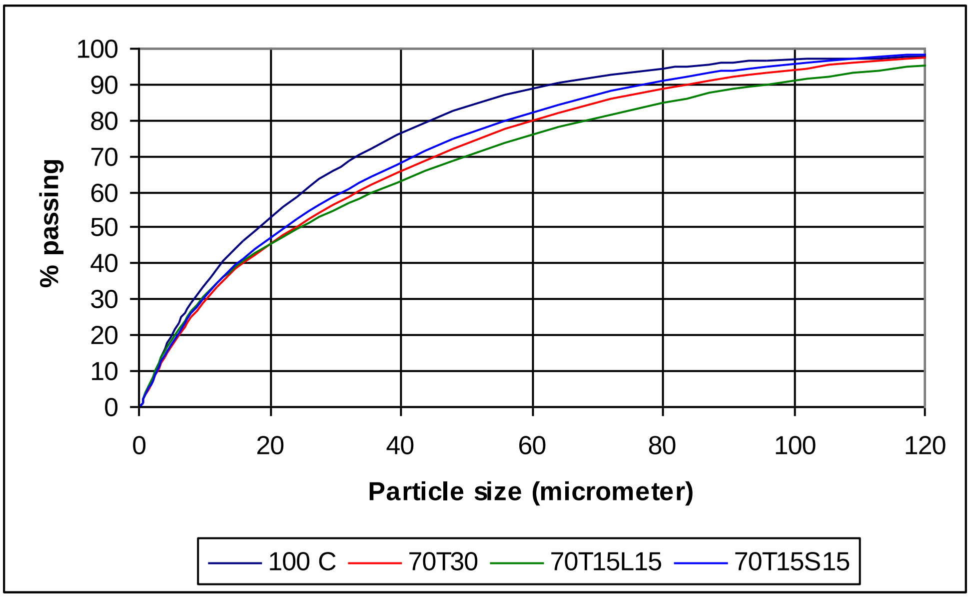

Figure 4.10: Particle size distributions of 30% mineral admixture incorporated interground triple blends. Limestone and GGBFS replaced half of the natural pozzolan (trass).

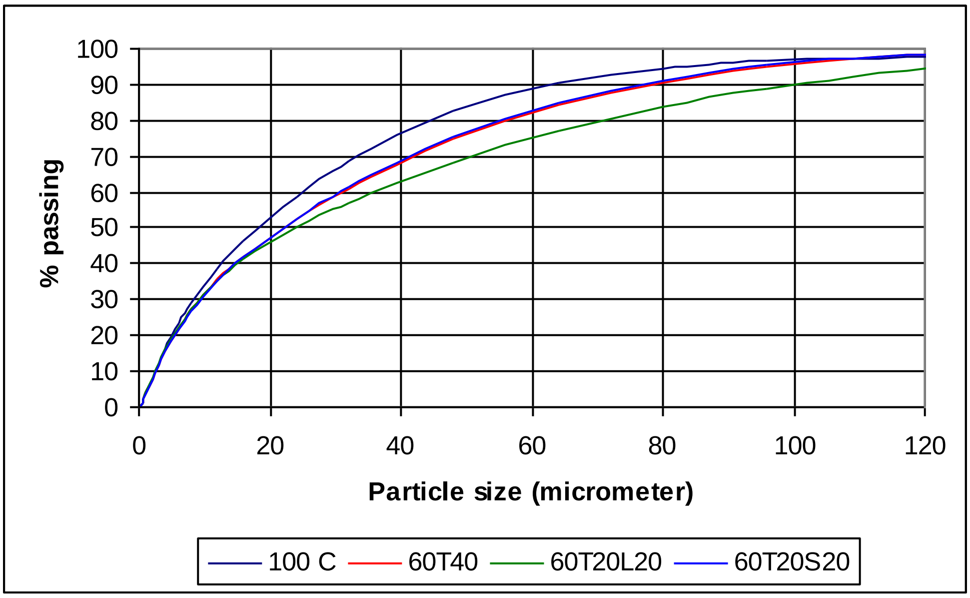

Figure 4.11: Particle size distributions of 40% mineral admixture incorporated interground triple blends. Limestone and GGBFS replaced half of the natural pozzolan (trass).

4.2.2.2 Limestone Replacement by Natural Pozzolan (trass) or GGBFS in Interground Cements

The psd's of the interground triple blends in which half of the limestone is replaced by either by natural pozzolan (trass) or GGBFS are given in Figure 4.12-13 and 14 for 20, 30 and 40% clinker replacement levels. It can be observed from these figures that if the third component in the blend is harder (GGBFS) than the other two (clinker and limestone), the psd shifts to the finer side. On the other hand, if the third component (natural pozzolan) is harder than only one of the other two components (limestone), the resulting cement will again have a finer particle size distribution however the effect is not as significant as the latter. Both effects become more pronounced as the amount of mineral admixture used increases.

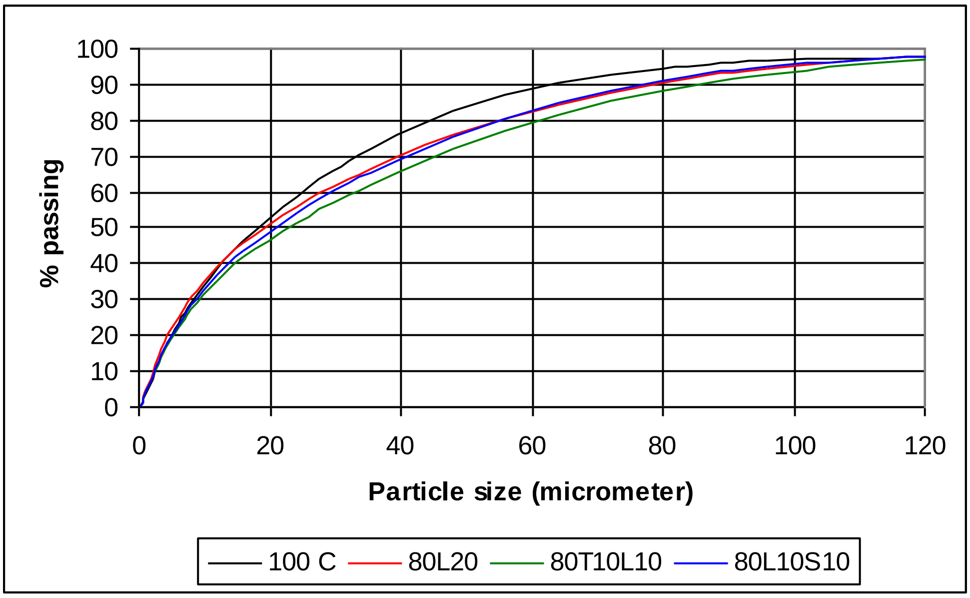

Figure 4.12: Particle size distributions of 20% mineral admixture incorporated interground triple blends. Natural pozzolan (trass) and GGBFS replaced half of the limestone.

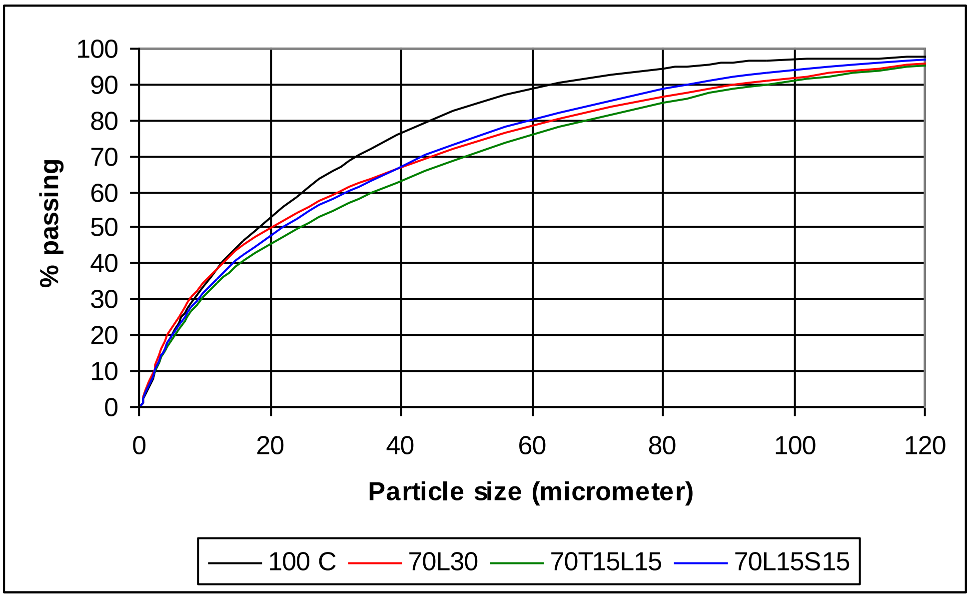

Figure 4.13: Particle size distributions of 30% mineral admixture incorporated interground triple blends. Natural pozzolan (trass) and GGBFS replaced half of the limestone.

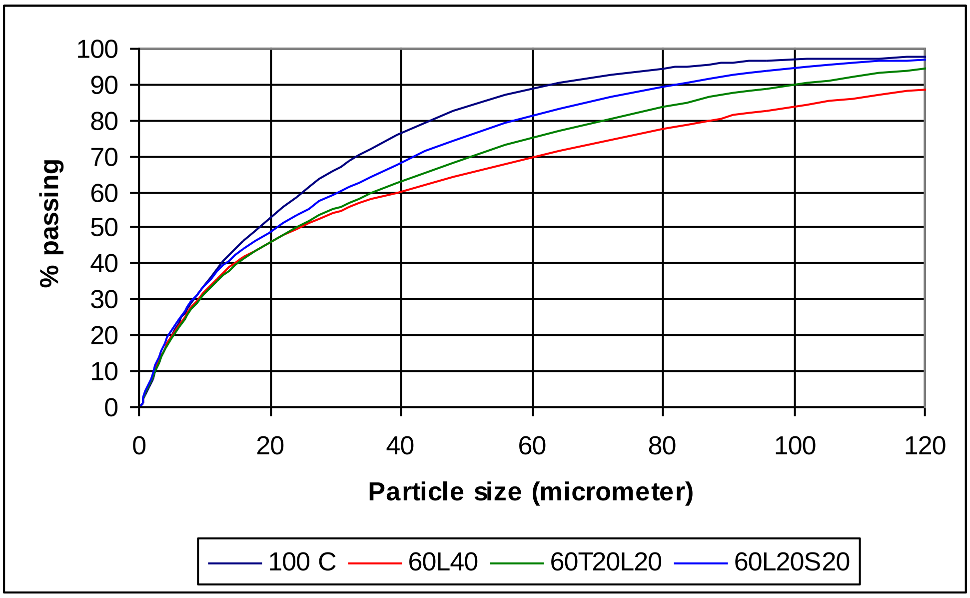

Figure 4.14: Particle size distributions of 40% mineral admixture incorporated interground triple blends. Natural pozzolan (trass) and GGBFS replaced half of the limestone.

4.2.2.3 GGBFS Replacement by Natural Pozzolan (Trass) or Limestone in Interground Cements

For the interground triple blends in which half of the GGBFS portion is replaced by either natural pozzolan (trass) or limestone, the psd’s are shifted to the coarser side as can be seen in Figure 4.15-16 and 17. It can be observed that the particle size of limestone addition cement is coarser than the natural pozzolan (trass) additive cement.

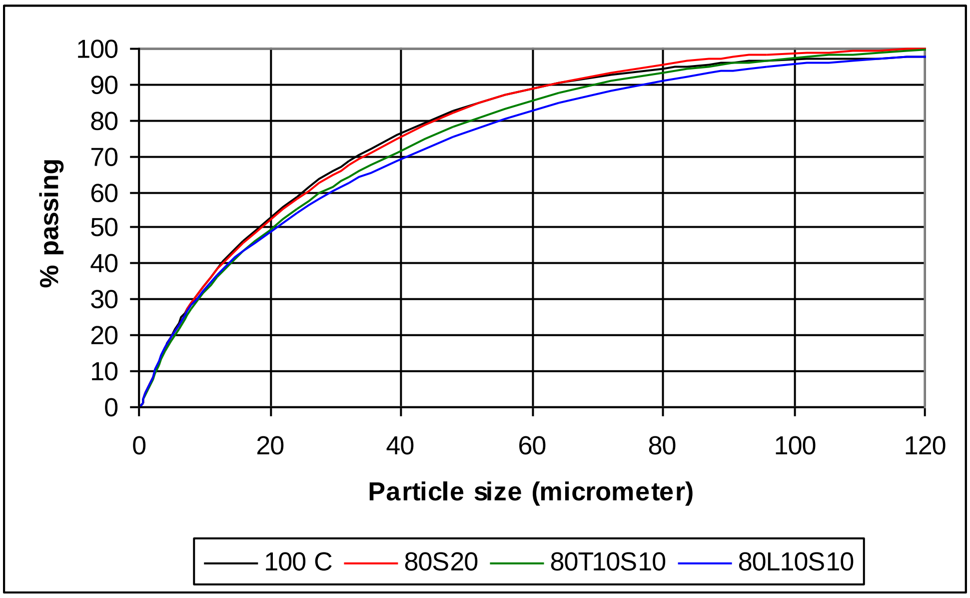

Figure 4.15: Particle size distributions of 20% mineral admixture incorporated interground triple blends. Natural pozzolan (trass) and limestone replaced half of the GGBFS.

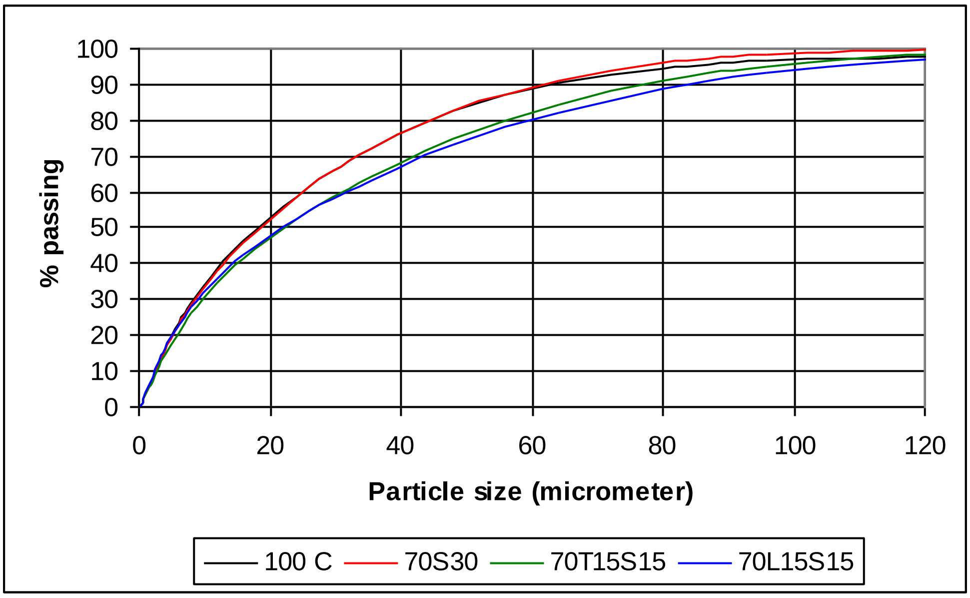

Figure 4.16: Particle size distributions of 30% mineral admixture incorporated interground triple blends. Natural pozzolan (trass) and limestone replaced half of the GGBFS.

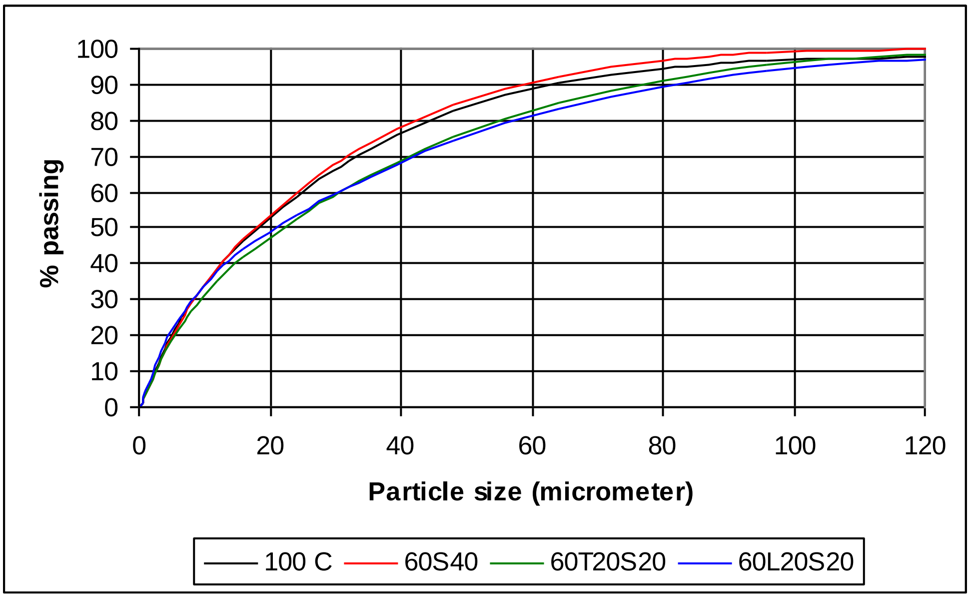

Figure 4.17: Particle size distributions of 40% mineral admixture incorporated interground triple blends. Natural pozzolan (trass) and limestone replaced half of the GGBFS.

4.2.3 Particle Size Distributions of Separately Ground Triple Blends

In separately ground and then blended triple blend cements the particle size distributions are not affected by the interaction of the individual ingredients as in the case of intergrinding. Therefore, the net effect of the mineral admixture contents on strength can be understood for the separately ground cements and the comparison of the strengths of interground and separately ground specimens will provide information on the effects of the interaction of particles of different ingredients.

The particle size distributions of separately ground triple blends together with the control and corresponding double blend cements are given in Figures 4.18 to 4.26.

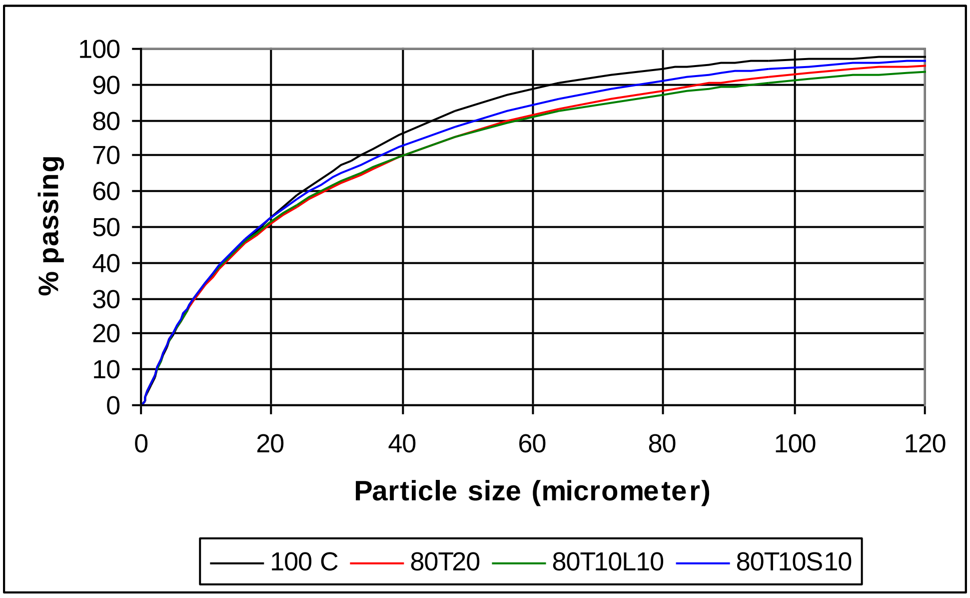

Figure 4.18: Particle size distributions of 20% mineral admixture incorporated separately ground triple blends. Limestone and GGBFS replaced half of the natural pozzolan (trass).

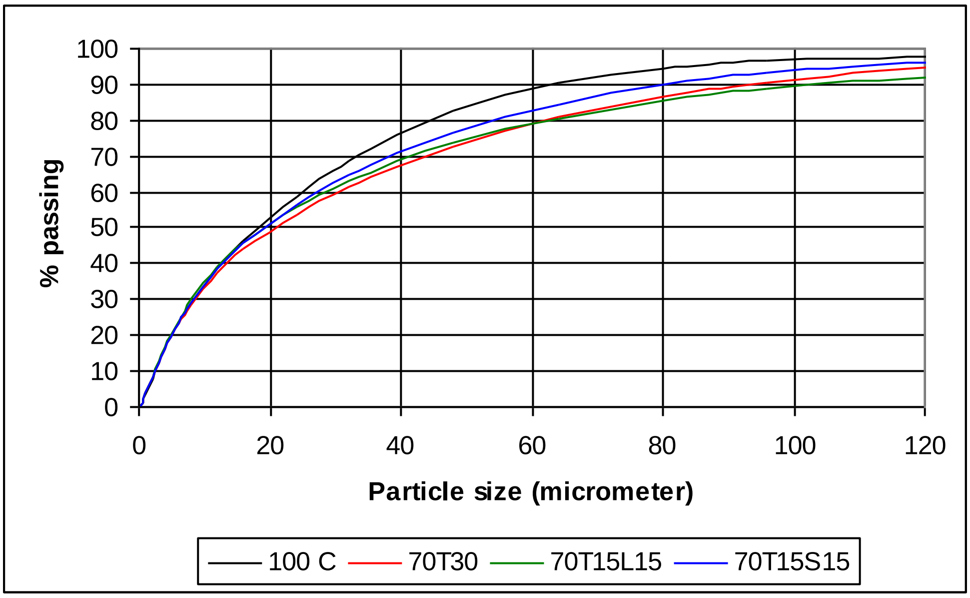

Figure 4.19: Particle size distributions of 30% mineral admixture incorporated separately ground triple blends. Limestone and GGBFS replaced half of the natural pozzolan (trass).

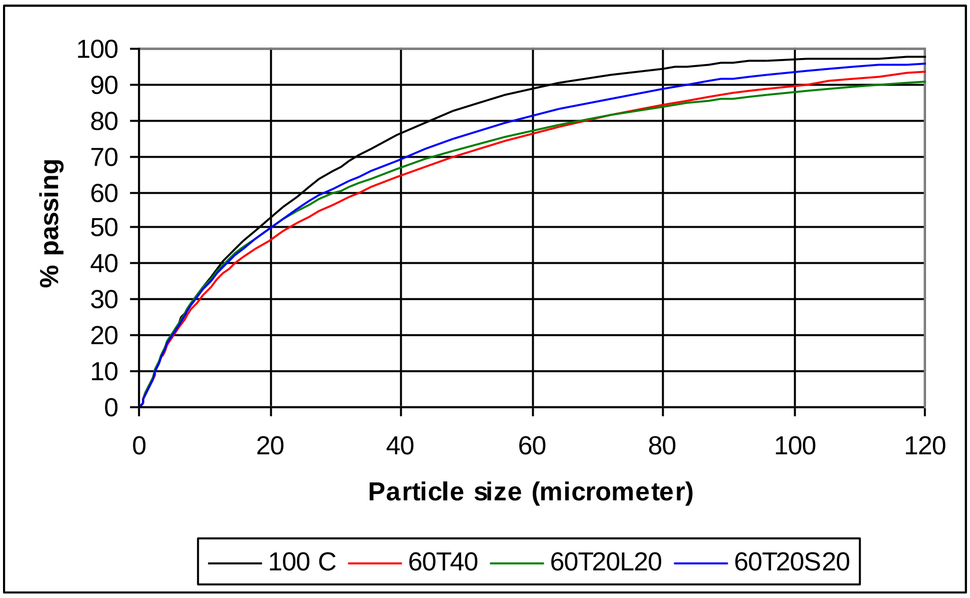

Figure 4.20: Particle size distributions of 40% mineral admixture incorporated separately ground triple blends. Limestone and GGBFS replaced half of the natural pozzolan (trass).

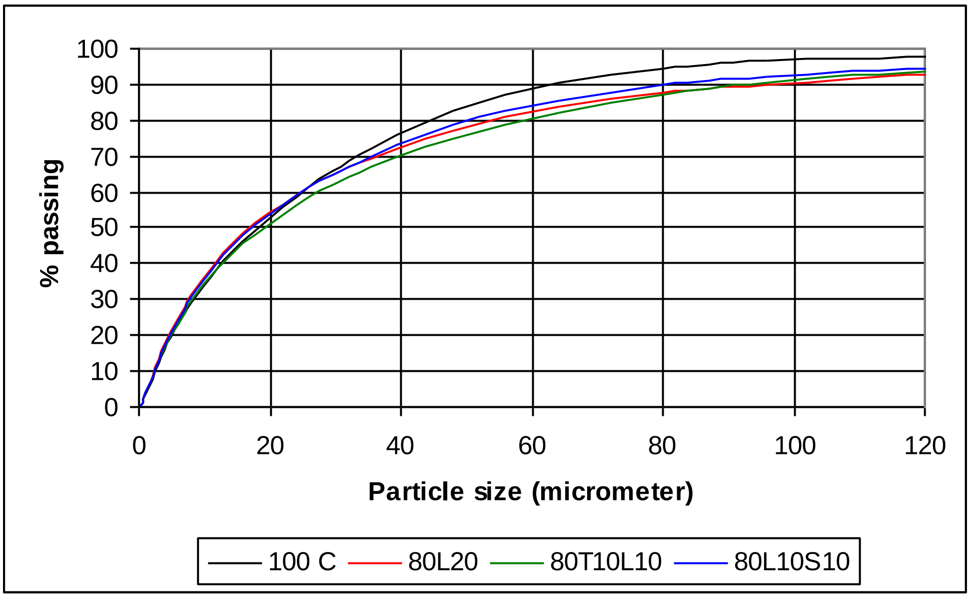

Figure 4.21: Particle size distributions of 20% mineral admixture incorporated separately ground triple blends. Natural pozzolan (trass) and GGBFS replaced half of the limestone.

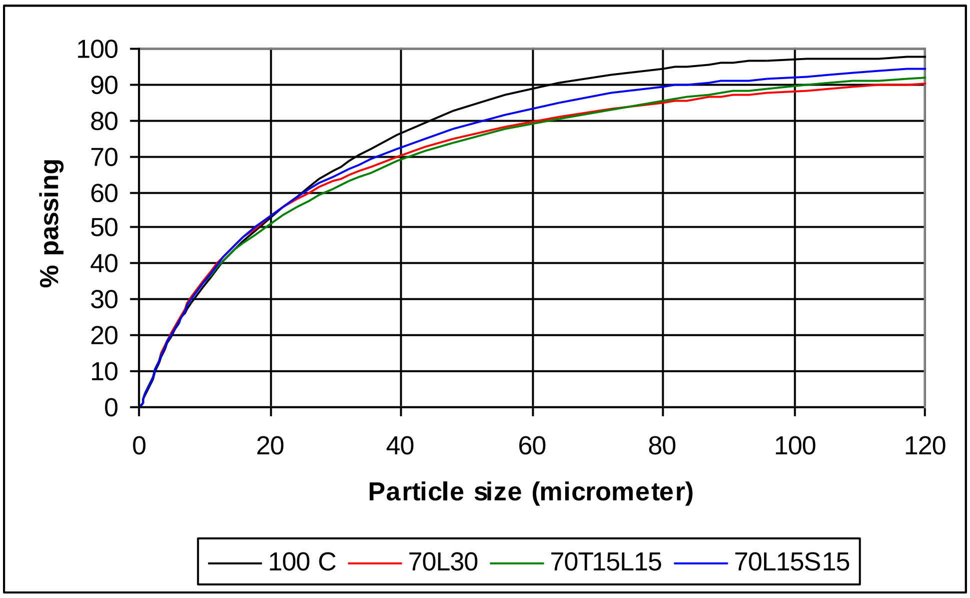

Figure 4.22: Particle size distributions of 30% mineral admixture incorporated separately ground triple blends. Natural pozzolan (trass) and GGBFS replaced half of the limestone.

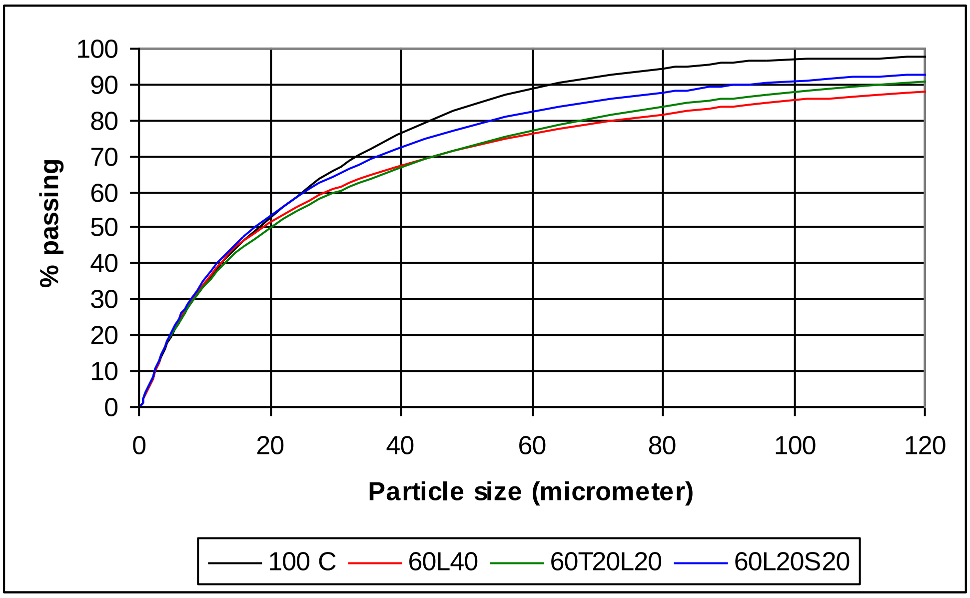

Figure 4.23: Particle size distributions of 40% mineral admixture incorporated separately ground triple blends. Natural pozzolan (trass) and GGBFS replaced half of the limestone.

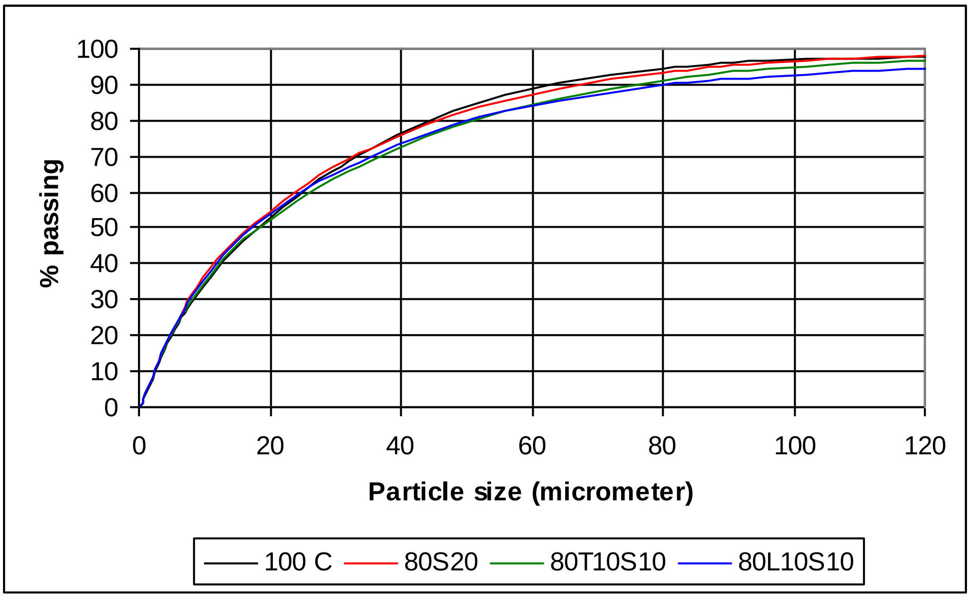

Figure 4.24: Particle size distributions of 20% mineral admixture incorporated separately ground triple blends. Natural pozzolan (trass) and limestone replaced half of the GGBFS.

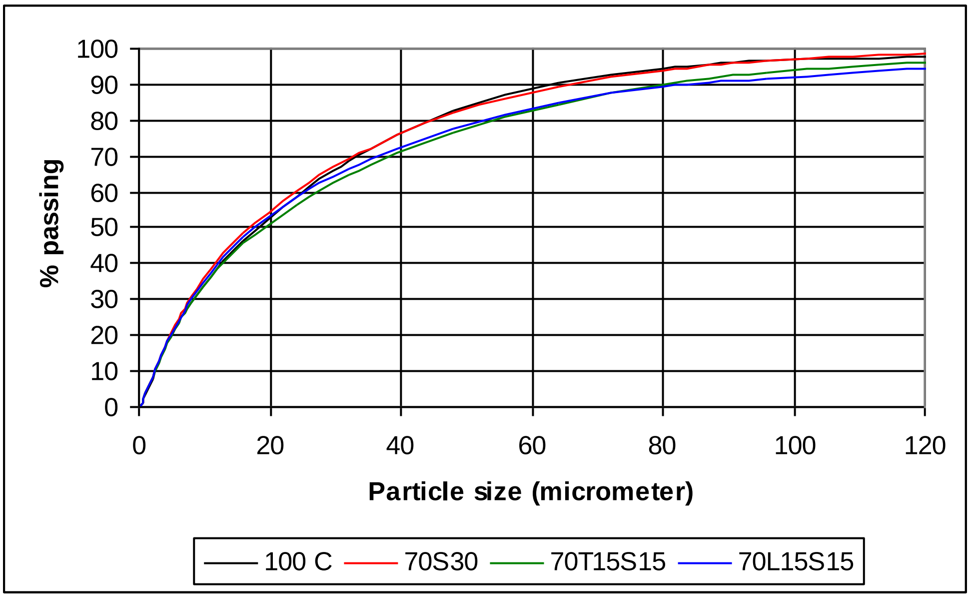

Figure 4.25: Particle size distributions of 30% mineral admixture incorporated separately ground triple blends. Natural pozzolan (trass) and limestone replaced half of the GGBFS.

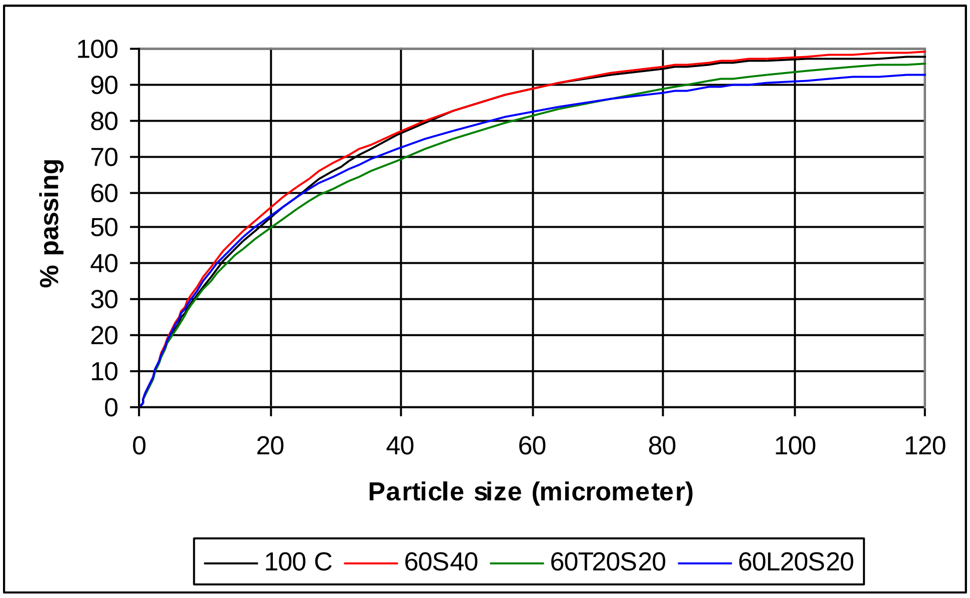

Figure 4.26: Particle size distributions of 40% mineral admixture incorporated separately ground triple blends. Natural pozzolan (trass) and limestone replaced half of the GGBFS.

4.2.4 General Comparison of the Particle Size Distribution Curves

According to Mehta and Monteiro (2006), particle size distribution curves of interground or separately ground cements are different. Particle size of >45 μm hydrate slowly and the ones >75 μm hardly ever hydrate completely. Although the cements investigated in this thesis are blended cements, still a comparison based on the above statement is given in Table 4.4.

Table 4.4: Amount of material finer than 75-45 μm in the cements Prepared

Sample	Amount finer than 75 μm (%)		Amount finer than 45 μm (%)	
	Interground	Separately ground.	Interground	Separately ground.
100 C	93	93	80	80
80T20	86	87	72	73
80T10L10	86	86	70	73
80T10S10	92	90	76	76
80L20	88	86	73	75
80L10S10	88	89	74	76
80S20	94	92	80	79
70T30	85	85	70	70
70T15L15	83	84	66	72
70T15S15	89	88	72	74
70L30	84	84	70	73
70L15S15	87	88	71	76
70S30	94	93	80	80
60T40	82	82	68	68
60T20L20	82	82	66	70
60T20S20	89	87	73	73
60L40	76	80	63	70
60L20S20	88	87	72	75
60S40	96	94	82	81

Although the particle size distributions are close to each other upon separate or intergrinding, there are some differences worth noting. The comparison of double blends composed of clinker+40% limestone and clinker+40% GGBFS is given in Figure 4.27 for particle sizes < 45μm, as an example.

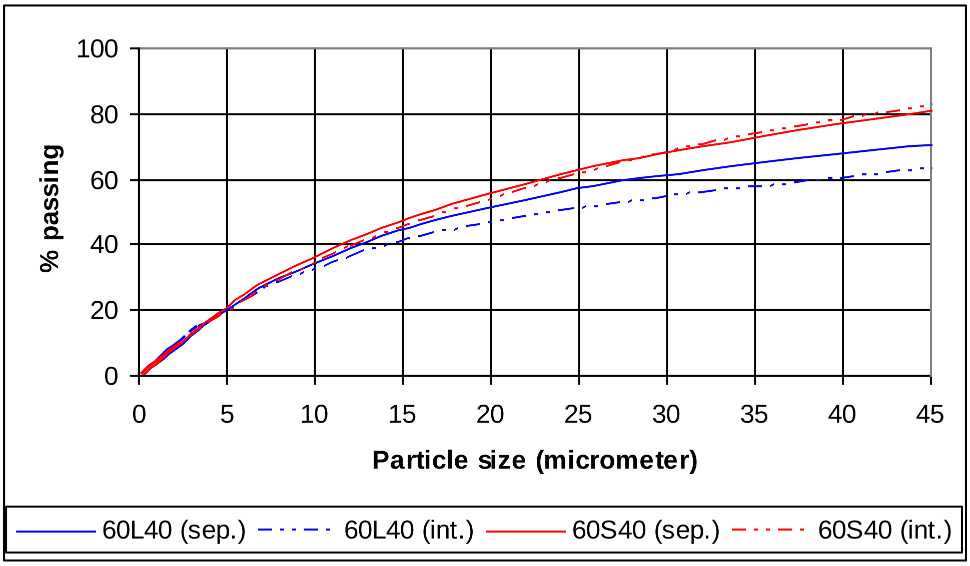

Figure 4.27: Comparison of the particle size distributions of interground and separately ground 40% GGBFS and Limestone double blends.

It can be seen from Figure 4.27 that for GGBFS which is harder than clinker the difference between particle size distributions of interground and separately ground cements is not significant, although separate grinding results in slightly more fine particles. However, separate grinding results in much more fine particles for particle sizes of between 15 and 45 μm in limestone incorporated double blends. Furthermore, upon intergrinding, interaction of GGBFS with clinker during grinding results in finer clinker and coarser GGBFS portions whereas interaction of clinker and limestone results in finer limestone and coarser clinker portions. On the other hand, separate grinding results in the original grading of the individual ingredients.

When a hard mineral admixture is used with a soft one in triple blends, a similar result to that of limestone in Figure 4.28 is observed. Separate grinding results in much more fine particles. Intergrinding, on the other hand, causes soft mineral admixture particles and the clinker and hard mineral admixture particles remain relatively coarser. An example for that is given in Fig. 4.28 for 20% GGBFS+20% Limestone triple blends.

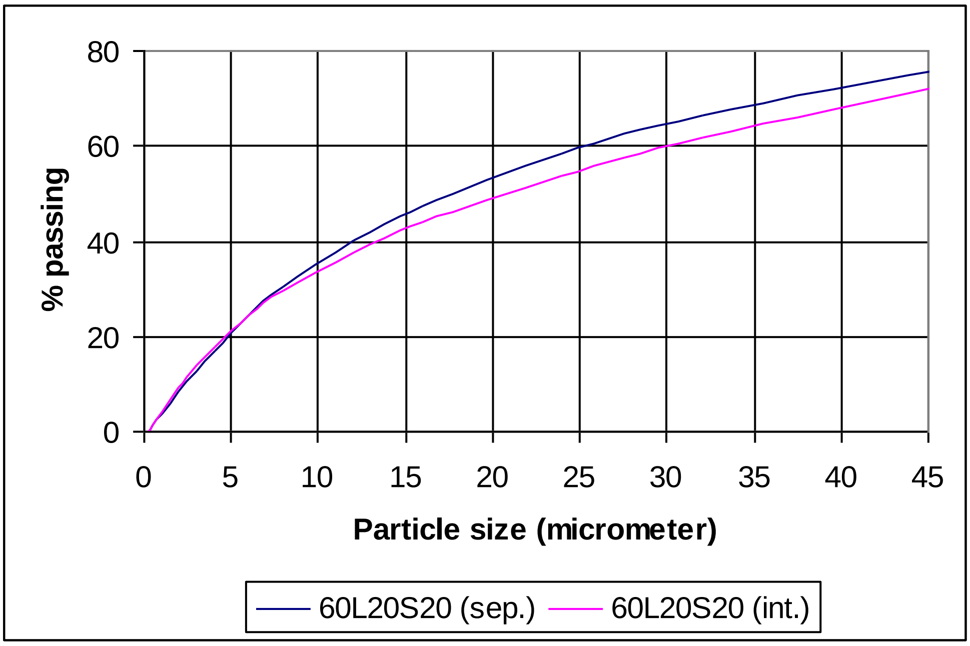

Figure 4.28: Comparison of the particle size distributions of interground and separately ground 20% GGBFS +20% Limestone triple blends.

4.3 COMPARISON OF WATER REQUIREMENTS FOR NORMAL CONSISTENCY

The normal consistency water requirements of the cements prepared in this investigation are given in Table 4.5.

Table 4.5: Normal Consistency Water Requirements

Sample	Normal Consistency Water (%, by weight)	
	Interground	Separately Ground
100 C	27.2	-
80T20	26.0	25.6
80T10L10	25.4	25.0
80T10S10	27.8	25.0
80L20	25.2	25.0
80L10S10	25.8	25.0
80S20	26.8	24.6
70T30	27.4	25.0
70T15L15	26.2	24.6
70T15S15	26.8	25.0
70L30	24.8	25.0
70L15S15	25.4	24.4
70S30	27.4	25.2
60T40	28.2	25.8
60T20L20	26.6	26.0
60T20S20	27.2	25.0
60L40	24.4	25.2
60L20S20	25.4	24.8
60S40	27.8	24.8

According to the results listed in Table 4.5, intergrinding the softer mineral admixtures (limestone and trass) with clinker results in cements slightly lower water requirement for normal consistency than the control cement. However, interground cements containing GGBFS which is harder than the clinker had more water requirements than the control. Since water requirement for a specified consistency, other parameters such as relative humidity and temperature being constant, depends on the fineness of cement, limestone and/or natural pozzolan (trass) incorporated interground blends having coarser clinker portion required less water whereas the GGBFS incorporated interground blends having finer clinker portion required more water.

It is interesting to note that the water requirement for normal consistency of the separately ground cements remained almost constant, without any dependence on the type and amount of mineral admixtures used.

Therefore, it can be stated that the fineness and the particle size distribution of the clinker portion of the blended cements plays the key role in changing the normal consistency water requirement.

Final and initial setting times and soundness expansion values of all cements used are given in Table 4.6. In this part of the experiments, noteworthy observation was that initial and final setting times and soundness expansion values of cement pastes were different in two grinding systems. In intergrinding, initial and final set values were higher than the separate grinding values. In the detailed study about additive amount or additive types did not give a consistent result about setting time values.

Table 4.6: Water Requirements, Final-Initial Setting Times and Soundness Expansions

	Sample	Water Amount (cc)	Water %	Initial set (min.)	Final set (min.)	Total expansion (mm)
	100 C	136	27.2	200	270	1
INTERGROUND	**80T20**	130	26.0	165	230	1
	80T10K10	127	25.4	170	230	1
	80T10C10	139	27.8	160	250	1
	80K20	126	25.2	130	230	1
	80K10C10	129	25.8	160	245	1
	80C20	134	26.8	200	245	1
	70T30	137	27.4	150	255	1
	70T15K15	131	26.2	120	240	1
	70T15C15	134	26.8	200	280	1
	70K30	124	24.8	150	230	1
	70K15C15	127	25.4	190	240	1
	70C30	137	27.4	200	260	2
	60T40	141	28.2	205	255	1
	60T20K20	133	26.6	205	260	1
	60T20C20	136	27.2	170	275	1
	60K40	122	24.4	140	280	2
	60K20C20	127	25.4	120	255	1
	60C40	139	27.8	180	295	1
SEP. GRINDING	**80T20**	128	25.6	160	225	2
	80T10L10	125	25.0	145	210	1
	80T10C10	125	25.0	155	215	1
	80L20	125	25.0	150	200	1
	80L10C10	125	25.0	155	220	1
	80C20	123	24.6	170	235	2
	70T30	125	25.0	155	220	1
	70T15L15	123	24.6	165	215	2
	70T15C15	125	25.0	170	225	5
	70L30	125	25.0	160	225	1
	70L15C15	122	24.4	160	230	3
	70C30	126	25.2	190	245	1
	60T40	129	25.8	170	230	0
	60T20L20	130	26.0	170	230	1
	60T20C20	125	25.0	170	240	1
	60L40	126	25.2	190	250	1
	60L20C20	124	24.8	170	220	1
	60C40	124	24.8	200	245	1

4.4 COMPARISON OF COMPRESSIVE STRENGTHS

Compressive strength determinations were based on two different methods namely, EN 196 and ASTM C 109. Water-cement ratio is constant in the former whereas it depends on the specified consistency of 110% flow in the latter. The reason why two different test methods were used lies in the fact that even slight differences in particle size distributions of the cements would change the water requirements for a specified consistency and differences in water requirements would result in different strengths, according to ASTM C 109. On the other hand, with the same reasoning, constant water-cement ratio would change the effort for a specified compaction. However, in EN 196, besides using a constant water-cement ratio a constant compaction effort is applied on all cement mortars.

The compressive strength test results determined according to EN 196 and ASTM C 109 are given in Tables 4.7 and 4.8, respectively. The results given in the tables are the average of 3 specimens (6 values).

Table 4.7: Compressive Strength Test Results (According to EN 196)

Sample	**2 Day Comp. Strength (MPa)**		**7 Day Comp. Strength (MPa)**		**28 Day Comp. Strength (MPa)**	
	Inter ground	**Sep. Ground**	**Inter ground**	**Sep. Ground**	**Inter ground**	**Sep. Ground**
100 C	21.8	-	37.7	-	48.7	-
80T20	14.3	15.5	24.1	26.6	37.1	38.3
80T10L10	12.0	15.8	23.6	26.9	32.6	35.9
80T10S10	14.6	16.9	24.5	27.0	36.8	42.6
80L20	14.0	17.7	24.1	28.0	33.6	37.4
80L10S10	14.8	17.2	24.8	28.4	34.8	37.2
80S20	15.8	16.9	26.1	26.3	39.9	42.8
70T30	9.5	13.6	19.1	22.5	30.3	35.6
70T15L15	10.0	14.2	19.0	23.5	27.3	34.5
70T15S15	11.8	12.8	22.2	20.7	33.8	36.9
70L30	8.5	14.5	17.4	23.8	24.0	33.2
70L15S15	10.1	14.0	18.9	22.3	28.1	35.0
70S30	15.4	13.6	25.4	22.3	40.4	37.1
60T40	6.8	10.3	13.7	18.3	22.3	29.6
60T20L20	6.6	11.4	13.0	19.8	19.4	28.3
60T20S20	9.3	9.6	16.3	17.3	30.1	30.2
60L40	3.9	10.6	8.0	19.0	12.8	25.5
60L20S20	9.0	11.3	16.6	20.3	25.4	30.6
60S40	11.4	9.7	19.5	18.4	34.6	37.4

Table 4.8: Compressive Strength Test Results (According to ASTM C 109)

Sample	2 Day Comp. Strength (MPa)		7 Day Comp. Strength (MPa)		28 Day Comp. Strength (MPa)	
	Inter ground	Sep. Ground	Inter ground	Sep. Ground	Inter ground	Sep. Ground
100 C	19.7	-	35.3	-	47.8	-
80T20	14.8	19.2	26.6	30.9	38.0	44.3
80T10L10	11.3	17.9	21.5	29.2	30.5	41.6
80T10S10	16.1	18.5	25.9	29.9	39.3	40.7
80L20	14.5	18.6	26.4	29.7	34.6	39.5
80L10S10	15.6	18.0	27.6	29.4	37.9	41.0
80S20	17.6	19.6	30.3	30.7	44.7	46.6
70T30	10.4	14.2	20.5	22.5	31.2	35.1
70T15L15	8.2	14.6	16.9	25.7	25.6	36.3
70T15S15	11.3	13.0	20.6	20.5	34.0	37.5
70L30	8.3	17.0	17.3	27.4	25.1	34.6
70L15S15	11.5	15.9	22.3	27.0	32.9	37.8
70S30	17.6	17.2	28.8	27.2	43.6	44.6
60T40	7.1	10.4	14.4	18.5	24.2	29.8
60T20L20	7.0	12.1	13.5	19.7	21.1	28.7
60T20S20	10.2	11.5	19.3	18.9	31.8	34.3
60L40	3.2	10.6	7.8	18.5	12.6	25.6
60L20S20	8.9	13.6	18.2	22.4	27.5	34.5
60S40	13.3	12.3	22.1	22.1	36.0	42.2

4.4.1 Compressive Strengths of Portland-Pozzolan Cements

The relationships between the natural pozzolan (trass) content and the compressive strength at 2, 7 and 28 days are given comparatively for interground and separately ground specimens in Figures 4.29 and 4.30 according to TS EN 196 and ASTM C 109 methods, respectively.

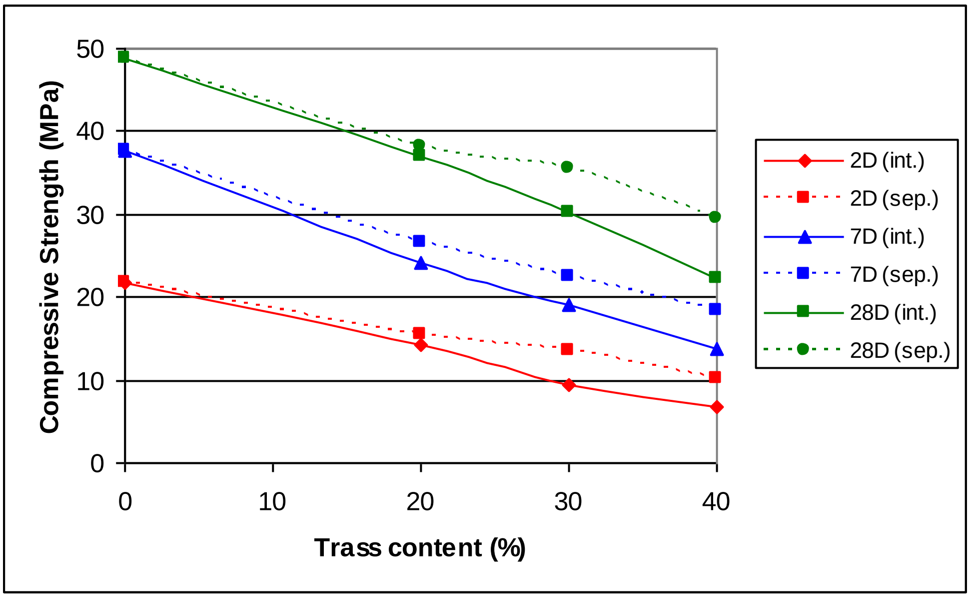

Figure 4.29: Natural pozzolan (trass) content-compressive strength relationship in Portland-pozzolan cements prepared by intergrinding and separate grinding and tested according to TS EN 196.

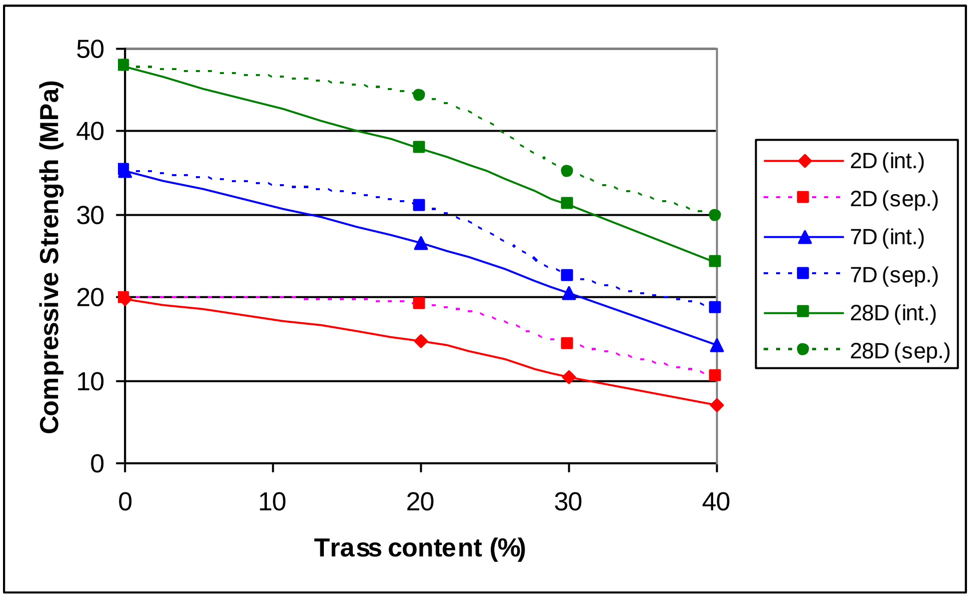

Figure 4.30: Natural pozzolan (trass) content-compressive strength relationship in Portland-pozzolan cements prepared by intergrinding and separate grinding and tested according to ASTM C 109.

It is obvious from both figures that separate grinding results in higher strengths at all ages tested simply because when compared with intergrinding, the clinker portion is finer and therefore more reactive. Since natural pozzolan (trass) is softer, intergrinding results in finer pozzolan but coarser clinker portions. Therefore, the strengths of interground Portland-pozzolan cements are lower and the difference between the strengths of the interground and separately ground cements is higher at early ages due to the fact that the finer clinker portion in the separately ground specimens makes more specific surface area available for hydration, thus increasing the rate of hydration. On the other hand, as the amount of natural pozzolan (trass) in the cement increases, strength decreases due to the corresponding reduction in the clinker portion. Comparison of TS EN and ASTM compressive test methods reveals that, in Portland-pozzolan cements the ASTM method results in higher compressive strengths in 20-30-40 % trass addition as shown in Figures 4.31 and 4.32 for interground and separately ground specimens, respectively.

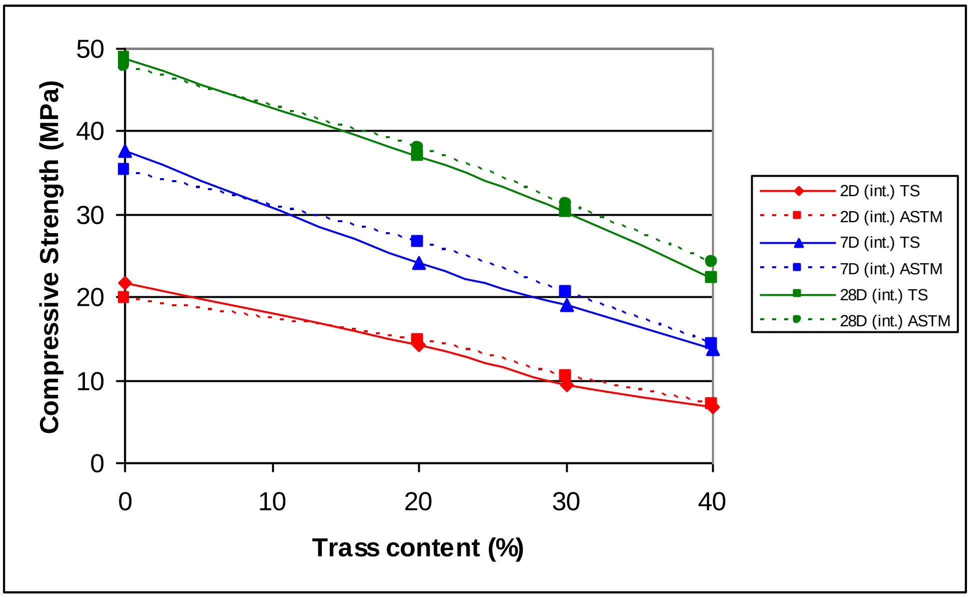

Figure 4.31: Comparison of strengths of interground Portland-pozzolan cements determined according to TS EN 196 and ASTM C 109.

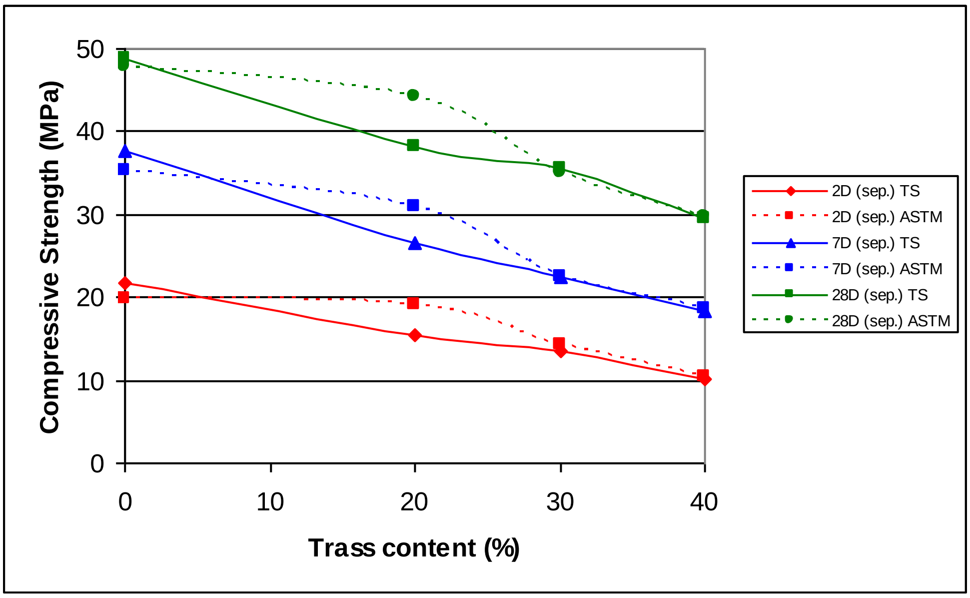

Figure 4.32: Comparison of strengths of separately ground Portland-pozzolan cements determined according to TS EN 196 and ASTM C 109.

4.4.2 Compressive Strengths of Portland-Limestone Cements

The relationships between the limestone content and the compressive strength at 2, 7 and 28 days are given comparatively for interground and separately ground specimens in Figures 4.33 and 4.34 according to TS EN 196 and ASTM C 109 methods, respectively.

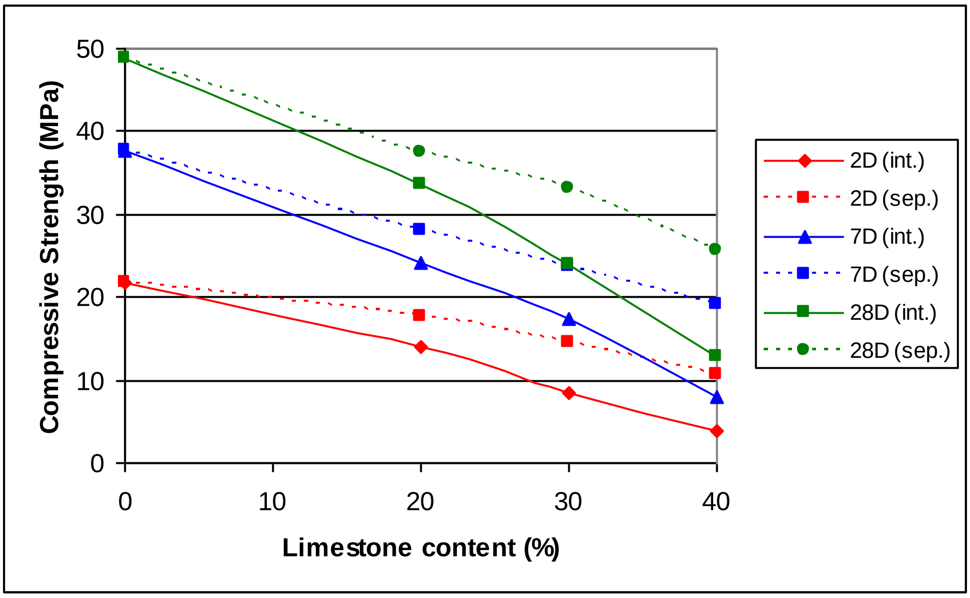

Figure 4.33: Limestone content-compressive strength relationship in Portland-limestone cements prepared by intergrinding and separate grinding and tested according to TS EN 196.

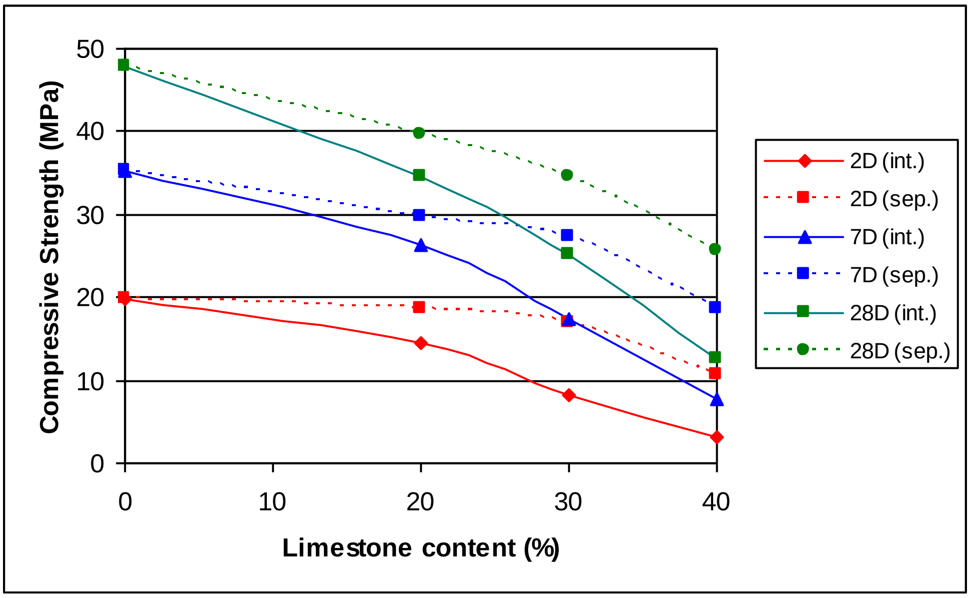

Figure 4.34: Limestone content-compressive strength relationship in Portland-limestone cements prepared by intergrinding and separate grinding and tested according to ASTM C 109.

A very similar discussion which is made for the effect of natural pozzolan (trass) incorporation on strength holds true for limestone incorporation. However, the effect of separate grinding is much more pronounced in Portland-limestone cements. In Figures 4.35 and 4.36, it can be observed that the strengths of ASTM and TS EN methods of Portland-limestone cement were very similar to each other.

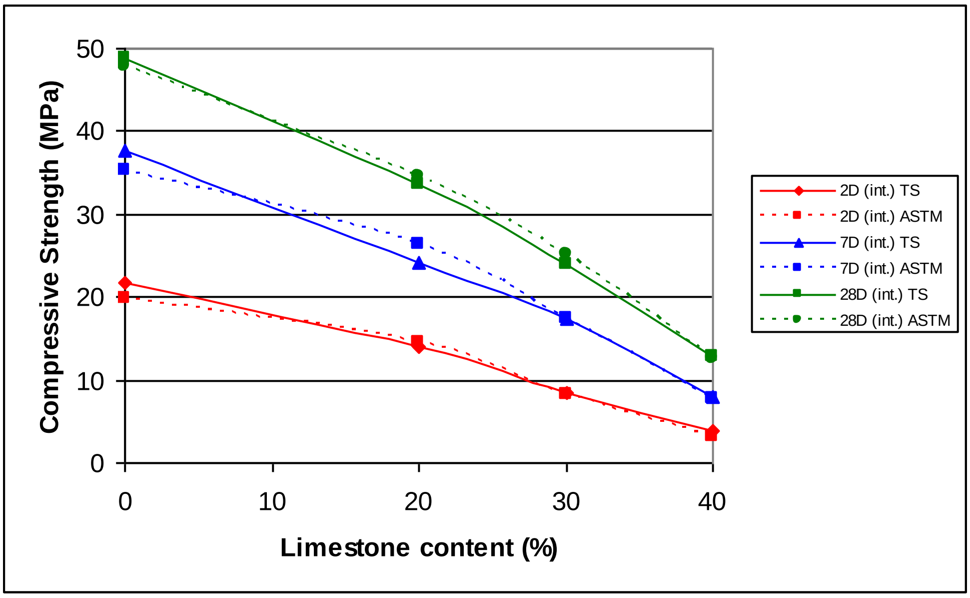

Figure 4.35: Comparison of strengths of interground portland-limestone cements determined according to TS EN 196 and ASTM C 109.

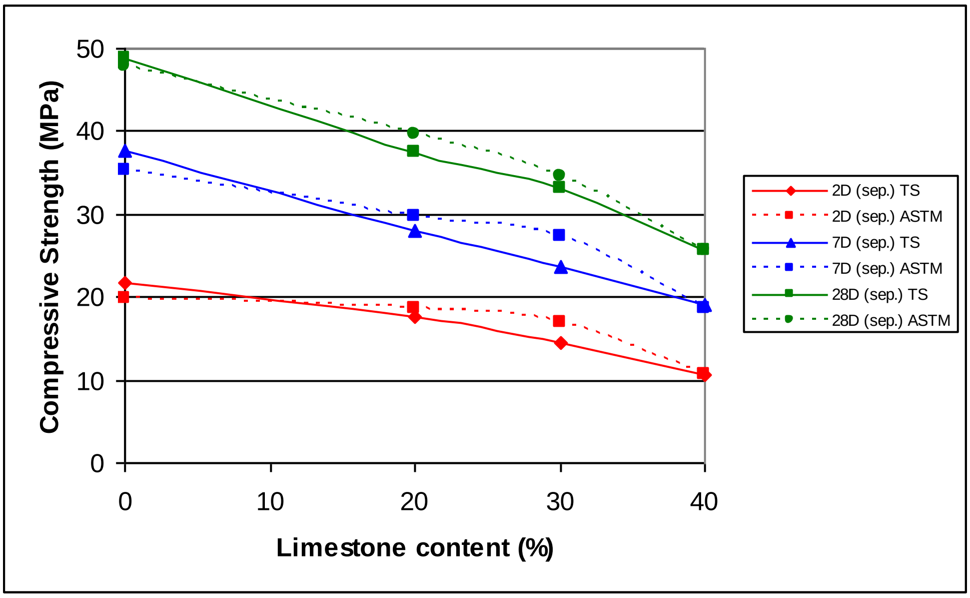

Figure 4.36: Comparison of strengths of separately ground Portland-limestone cements determined according to TS EN 196 and ASTM C 109.

4.4.3 Compressive Strengths of Portland-GGBFS Cements

The relationships between the slag content and the compressive strength at 2, 7 and 28 days are given comparatively for interground and separately ground specimens in Figures 4.37 and 4.38 according to TS EN 196 and ASTM C 109 methods, respectively.

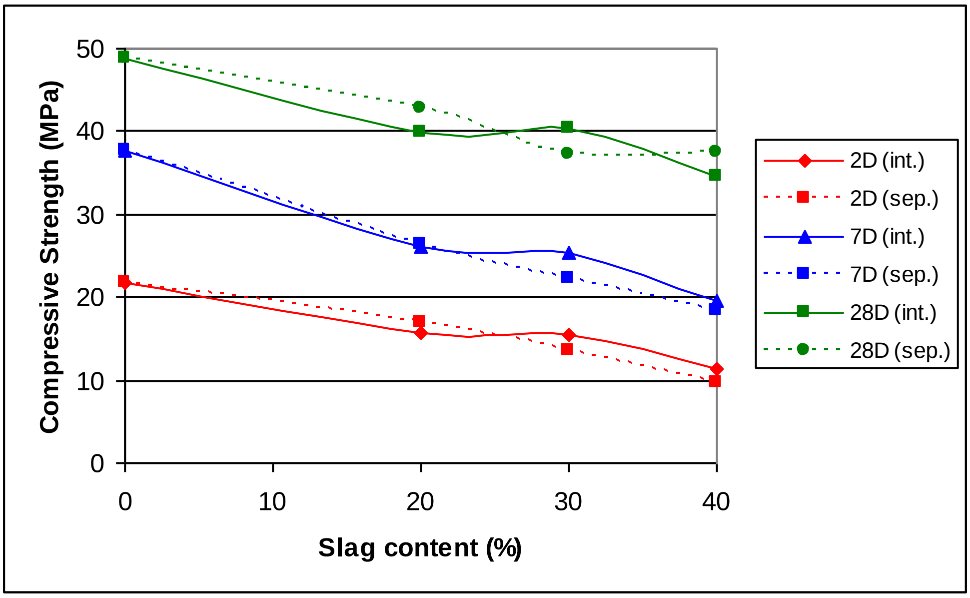

Figure 4.37: Slag content-compressive strength relationship in Portland-GGBFS cements prepared by intergrinding and separate grinding and tested according to TS EN 196.

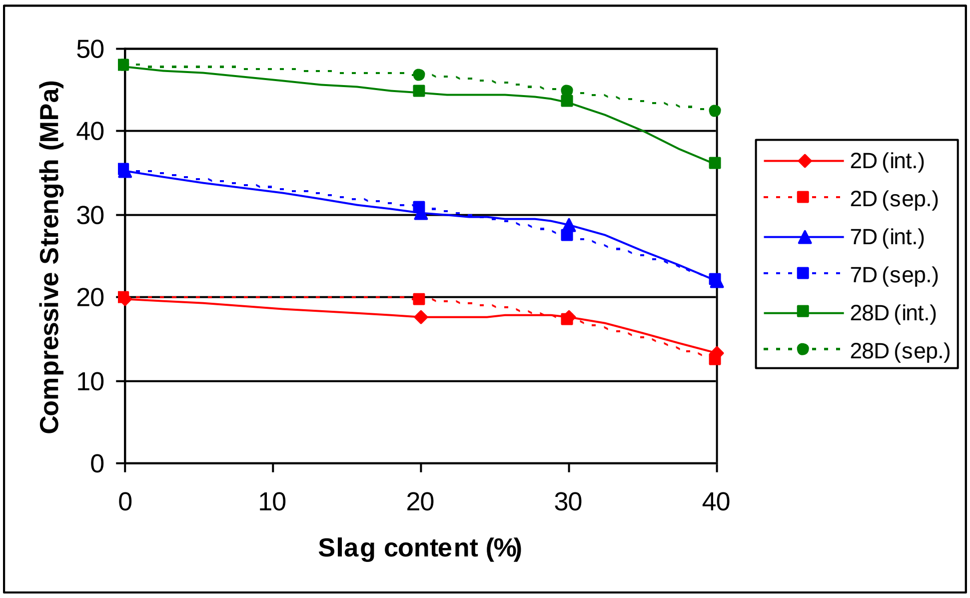

Figure 4.38: Slag content-compressive strength relationship in Portland-GGBFS cements prepared by intergrinding and separate grinding and tested according to ASTM C 109.

Since slag is harder, intergrinding results have fine clinker portions. Therefore, while the compressive strength of limestone and trass additive cements sharply decreasing with increasing the additive amount, in GGBFS-cement this decrease is not as sharp as the others.

In Figures 4.39 and 4.40, two different standards are compared again. It can be observed that the strengths in ASTM standards are higher than the TS EN standards both in intergrinding and separate grinding. However, the strength difference of the two standards increased relative to the trass and limestone additive cements.

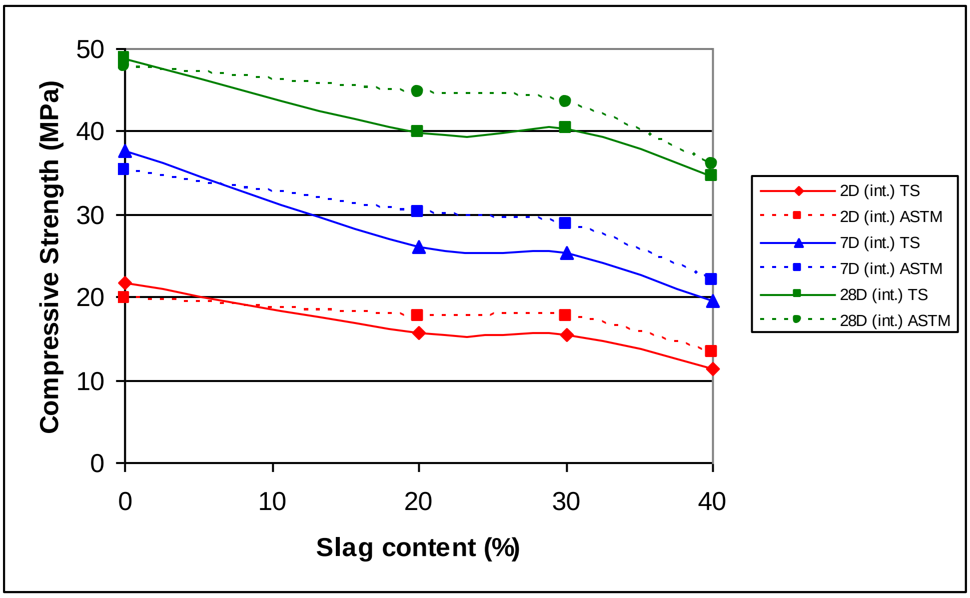

Figure 4.39: Comparison of strengths of interground Portland-GGBFS cements determined according to TS EN 196 and ASTM C 109.

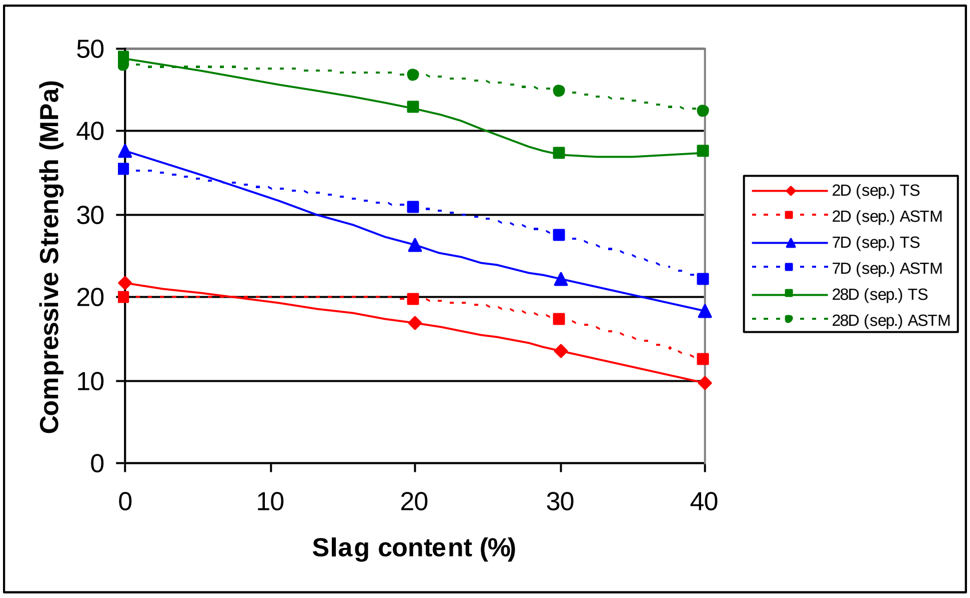

Figure 4.40: Comparison of strengths of separately ground Portland-GGBFS cements determined according to TS EN 196 and ASTM C 109.

CHAPTER 5

CONCLUSIONS

In this study, granulated blast furnace slag, natural pozzolan (trass) and limestone incorporated CEM II B cements produced by intergrinding and separate grinding were compared.

Although the Blaine fineness values of the cements were approximately the same in all cements produced, their particle size distributions were different. In the intergrinding of the double-blend cements in which there was only one type of mineral admixture, the relative grindability of the admixture with respect to clinker affected the particle size distributions. For example, clinker portion has finer particles relative to mixture in GBFS-incorporated cement due to the additional grinding effect of GBFS due to its higher hardness. On the other hand, additive materials had finer particles than the clinker in trass and limestone incorporated cements. However, in separate grinding, the particle size distribution of each ingredient remained unaffected by the other.

In the intergrinding of the triple blends, if the third component in the mixture is harder (GGBFS) than the other two (clinker and natural pozzolan (trass) or limestone), the particle size distribution shifts to the finer side. On the other hand, if the third component is softer (limestone or trass), the resulting cement will have a coarser particle size distribution.

In separately ground and then blended triple blends, the particle size distributions are not affected by the interaction of the individual ingredients as in the case of intergrinding.

The water requirement was related with the fineness of both the cement and clinker portion of the cement. Limestone and/or natural pozzolan (trass) incorporated interground blends having coarser clinker portion required less water whereas the GGBFS incorporated interground blends having finer clinker portion required more water.

It is interesting to note that the water requirement for normal consistency of the separately ground cements remained almost constant, without any dependence on the type and amount of mineral admixtures used.

The basic conclusion of this study was that separately ground blended cements had higher strength than the interground cements of the same fineness for all of the three admixture types and proportions used.

In all of the blended cement types, by increasing the mineral admixture amount in the cement, strength decrease due to the corresponding reduction in the clinker portion was observed. This negative effect is more pronounced in limestone incorporated cements.

In the GGBFS-incorporated cements, intergrinding resulted in finer clinker portions. Therefore, while the compressive strength of limestone and trass incorporated cements decreased sharply with increasing admixture amount, it was not that great in GGBFS-incorporated cements.

It can be observed that the strength values obtained according to ASTM C 109 for all cement types were slightly higher than those obtained according to TS EN 196 due to using different water proportions in ASTM C 109. The strength difference of the two standards was higher in GGBFS-incorporated cements.

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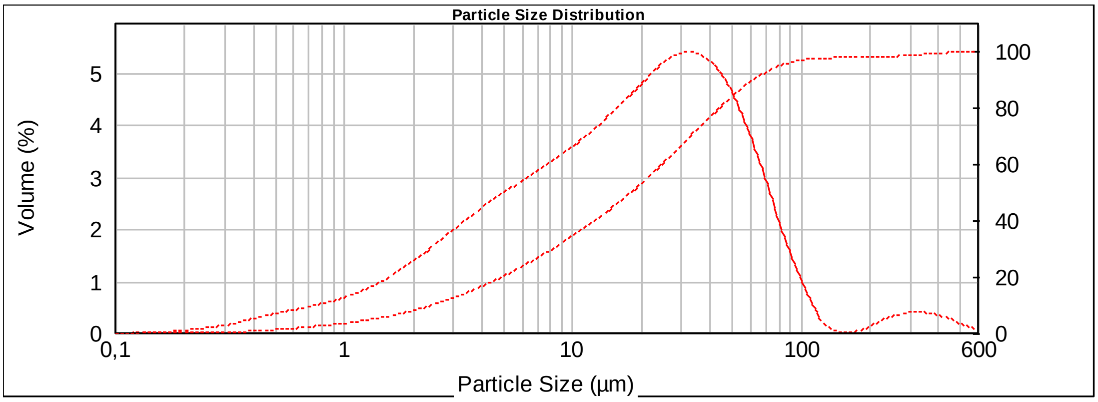
APPENDIX A

PARTICLE SIZE ANALYSIS OF SAMPLES

A.1 Particle size analysis result for “100 C”

Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0,010	0,00	0,105	0,00	1,096	0,71	11,482	3,51	120,226	0,15	1258,925	0,00
0,011	0,00	0,120	0,00	1,259	0,81	13,183	3,72	138,038	0,03	1445,440	0,00
0,013	0,00	0,138	0,01	1,445	0,94	15,136	3,95	158,489	0,03	1659,587	0,00
0,015	0,00	0,158	0,02	1,660	1,09	17,378	4,19	181,970	0,08	1905,461	0,00
0,017	0,00	0,182	0,04	1,905	1,26	19,953	4,43	208,930	0,20	2187,762	0,00
0,020	0,00	0,209	0,07	2,188	1,44	22,909	4,65	239,883	0,30	2511,886	0,00
0,023	0,00	0,240	0,10	2,512	1,62	26,303	4,81	275,423	0,35	2884,032	0,00
0,026	0,00	0,275	0,13	2,884	1,81	30,200	4,88	316,228	0,36	3311,311	0,00
0,030	0,00	0,316	0,18	3,311	2,00	34,674	4,82	363,078	0,33	3801,894	0,00
0,035	0,00	0,363	0,23	3,802	2,18	39,811	4,61	416,869	0,26	4365,158	0,00
0,040	0,00	0,417	0,29	4,365	2,34	45,709	4,25	478,630	0,15	5011,872	0,00
0,046	0,00	0,479	0,35	5,012	2,50	52,481	3,73	549,541	0,06	5754,399	0,00
0,052	0,00	0,550	0,40	5,754	2,66	60,256	3,08	630,957	0,00	6606,934	0,00
0,060	0,00	0,631	0,44	6,607	2,81	69,183	2,37	724,436	0,00	7585,776	0,00
0,069	0,00	0,724	0,49	7,586	2,97	79,433	1,66	831,764	0,00	8709,636	0,00
0,079	0,00	0,832	0,55	8,710	3,13	91,201	1,04	954,993	0,00	10000,000	
0,091	0,00	0,955	0,62	10,000	3,32	104,713	0,50	1096,478	0,00		
0,105		1,096		11,482		120,226		1258,925			



A.2 Particle size analysis result for “80 T 20 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

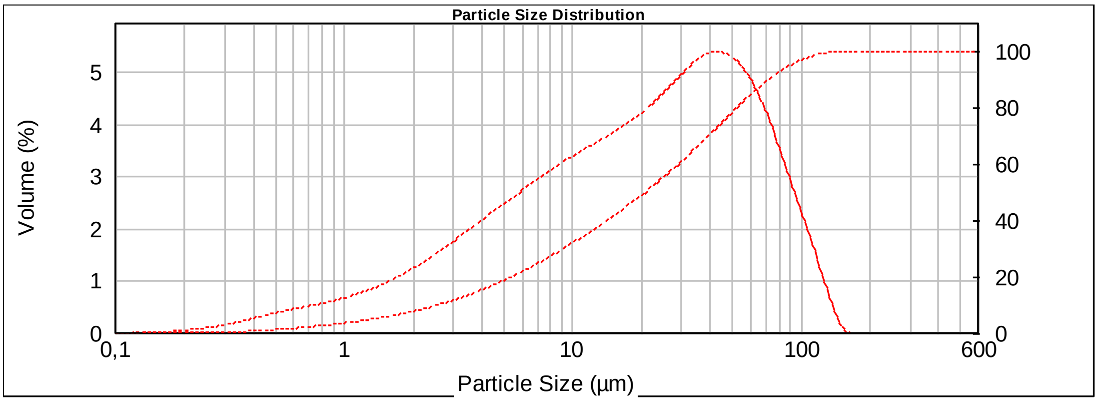
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,13
0,316	0,18
0,363	0,24
0,417	0,30
0,479	0,35
0,550	0,40
0,631	0,45
0,724	0,50
0,832	0,55
0,955	0,61
1,096	

Size (µm)	Volume In %
1,096	0,68
1,259	0,77
1,445	0,87
1,660	0,99
1,905	1,12
2,188	1,27
2,512	1,44
2,884	1,61
3,311	1,78
3,802	1,96
4,365	2,13
5,012	2,30
5,754	2,47
6,607	2,64
7,586	2,81
8,710	2,96
10,000	3,11
11,482	

Size (µm)	Volume In %
11,482	3,24
13,183	3,38
15,136	3,52
17,378	3,68
19,953	3,87
22,909	4,10
26,303	4,34
30,200	4,58
34,674	4,76
39,811	4,85
45,709	4,80
52,481	4,57
60,256	4,16
69,183	3,60
79,433	2,93
91,201	2,23
104,713	1,54
120,226	

Size (µm)	Volume In %
120,226	0,83
138,038	0,18
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.3 Particle size analysis result for “80T10L10 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

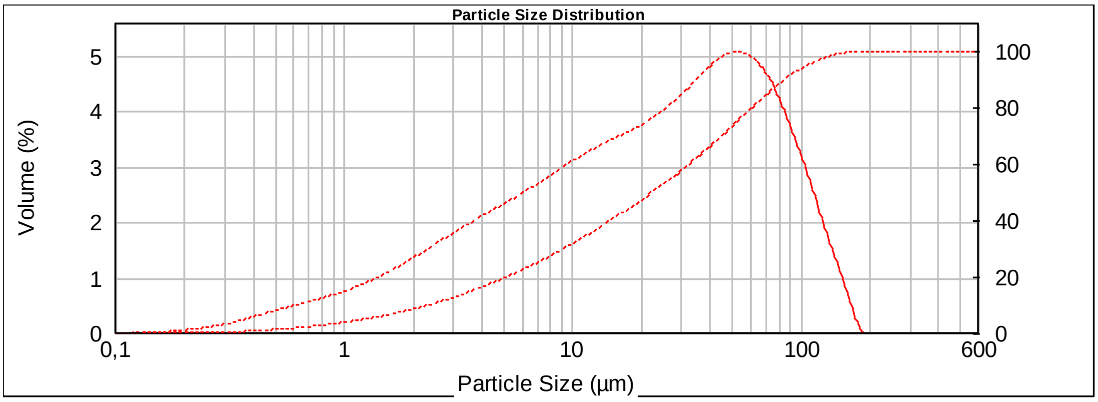
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,13
0,316	0,18
0,363	0,25
0,417	0,31
0,479	0,37
0,550	0,43
0,631	0,49
0,724	0,55
0,832	0,61
0,955	0,69
1,096	

Size (µm)	Volume In %
1,096	0,77
1,259	0,86
1,445	0,97
1,660	1,10
1,905	1,23
2,188	1,36
2,512	1,50
2,884	1,64
3,311	1,77
3,802	1,90
4,365	2,03
5,012	2,15
5,754	2,28
6,607	2,42
7,586	2,56
8,710	2,71
10,000	2,85
11,482	

Size (µm)	Volume In %
11,482	2,98
13,183	3,10
15,136	3,20
17,378	3,31
19,953	3,43
22,909	3,59
26,303	3,78
30,200	3,99
34,674	4,22
39,811	4,42
45,709	4,55
52,481	4,56
60,256	4,41
69,183	4,09
79,433	3,61
91,201	3,01
104,713	2,35
120,226	

Size (µm)	Volume In %
120,226	1,68
138,038	1,03
158,489	0,33
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.4 Particle size analysis result for “80T10S10 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

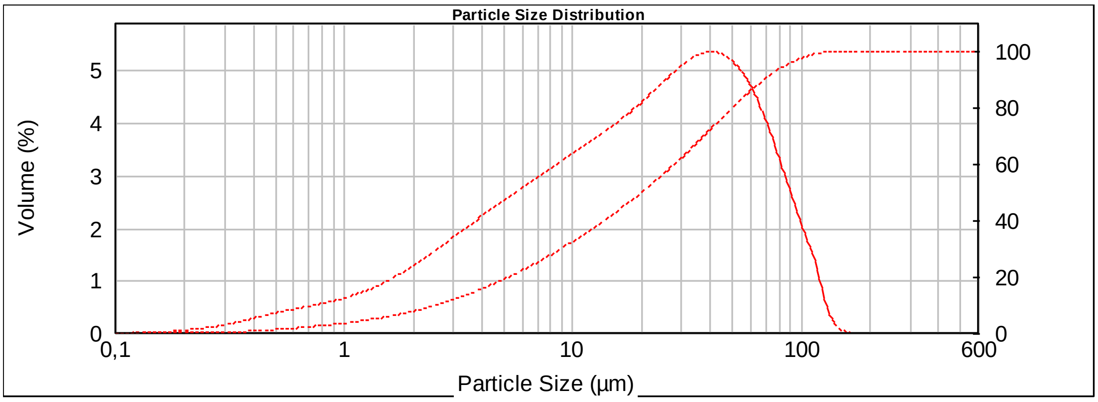
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,13
0,316	0,18
0,363	0,24
0,417	0,30
0,479	0,35
0,550	0,40
0,631	0,44
0,724	0,49
0,832	0,54
0,955	0,60
1,096	

Size (µm)	Volume In %
1,096	0,68
1,259	0,77
1,445	0,88
1,660	1,01
1,905	1,16
2,188	1,32
2,512	1,49
2,884	1,66
3,311	1,84
3,802	2,01
4,365	2,18
5,012	2,34
5,754	2,50
6,607	2,66
7,586	2,82
8,710	2,98
10,000	3,14
11,482	

Size (µm)	Volume In %
11,482	3,30
13,183	3,47
15,136	3,65
17,378	3,84
19,953	4,05
22,909	4,27
26,303	4,49
30,200	4,67
34,674	4,80
39,811	4,82
45,709	4,72
52,481	4,44
60,256	4,00
69,183	3,41
79,433	2,73
91,201	2,01
104,713	1,37
120,226	

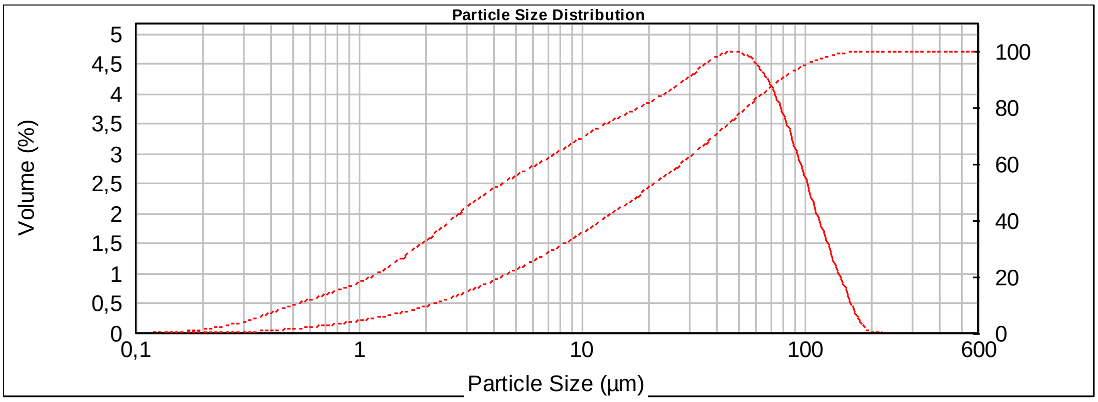
Size (µm)	Volume In %
120,226	0,52
138,038	0,09
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.5 Particle size analysis result for “80L20 Interground”

Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0,010	0,00	0,105	0,00	1,096	0,86	11,482	3,11	120,226	1,26	1258,925	0,00
0,011	0,00	0,120	0,00	1,259	0,98	13,183	3,21	138,038	0,75	1445,440	0,00
0,013	0,00	0,138	0,01	1,445	1,11	15,136	3,31	158,489	0,28	1659,587	0,00
0,015	0,00	0,158	0,03	1,660	1,25	17,378	3,41	181,970	0,04	1905,461	0,00
0,017	0,00	0,182	0,05	1,905	1,41	19,953	3,51	208,930	0,00	2187,762	0,00
0,020	0,00	0,209	0,08	2,188	1,57	22,909	3,63	239,883	0,00	2511,886	0,00
0,023	0,00	0,240	0,11	2,512	1,74	26,303	3,77	275,423	0,00	2884,032	0,00
0,026	0,00	0,275	0,15	2,884	1,90	30,200	3,92	316,228	0,00	3311,311	0,00
0,030	0,00	0,316	0,21	3,311	2,04	34,674	4,07	363,078	0,00	3801,894	0,00
0,035	0,00	0,363	0,28	3,802	2,17	39,811	4,19	416,869	0,00	4365,158	0,00
0,040	0,00	0,417	0,36	4,365	2,30	45,709	4,23	478,630	0,00	5011,872	0,00
0,046	0,00	0,479	0,42	5,012	2,41	52,481	4,16	549,541	0,00	5754,399	0,00
0,052	0,00	0,550	0,49	5,754	2,52	60,256	3,94	630,957	0,00	6606,934	0,00
0,060	0,00	0,631	0,55	6,607	2,63	69,183	3,56	724,436	0,00	7585,776	0,00
0,069	0,00	0,724	0,62	7,586	2,75	79,433	3,05	831,764	0,00	8709,636	0,00
0,079	0,00	0,832	0,69	8,710	2,87	91,201	2,45	954,993	0,00	10000,000	
0,091	0,00	0,955	0,77	10,000	2,99	104,713	1,84	1096,478	0,00		
0,105		1,096		11,482		120,226		1258,925			



A.6 Particle size analysis result for “80L10S10 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

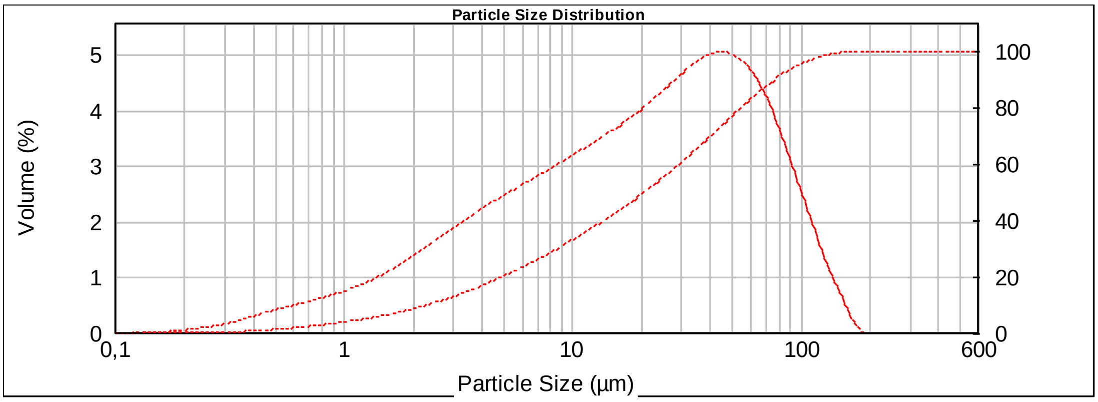
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,32
0,479	0,38
0,550	0,44
0,631	0,50
0,724	0,55
0,832	0,62
0,955	0,69
1,096	

Size (µm)	Volume In %
1,096	0,77
1,259	0,87
1,445	0,99
1,660	1,12
1,905	1,26
2,188	1,41
2,512	1,57
2,884	1,73
3,311	1,88
3,802	2,02
4,365	2,16
5,012	2,29
5,754	2,42
6,607	2,54
7,586	2,67
8,710	2,80
10,000	2,94
11,482	

Size (µm)	Volume In %
11,482	3,07
13,183	3,21
15,136	3,36
17,378	3,53
19,953	3,71
22,909	3,90
26,303	4,11
30,200	4,30
34,674	4,46
39,811	4,55
45,709	4,55
52,481	4,41
60,256	4,11
69,183	3,66
79,433	3,07
91,201	2,43
104,713	1,78
120,226	

Size (µm)	Volume In %
120,226	1,18
138,038	0,66
158,489	0,19
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.7 Particle size analysis result for “80S20 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

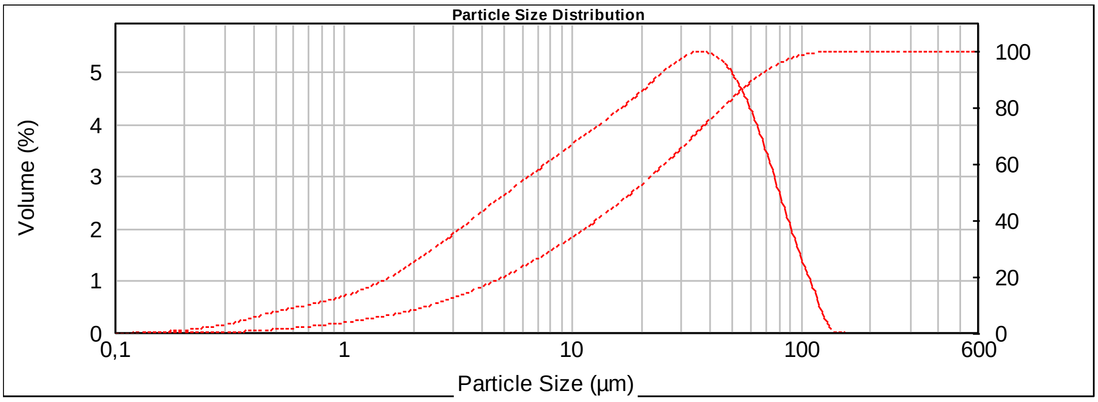
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,31
0,479	0,37
0,550	0,42
0,631	0,47
0,724	0,52
0,832	0,58
0,955	0,65
1,096	

Size (µm)	Volume In %
1,096	0,72
1,259	0,82
1,445	0,93
1,660	1,06
1,905	1,21
2,188	1,38
2,512	1,55
2,884	1,74
3,311	1,92
3,802	2,10
4,365	2,28
5,012	2,46
5,754	2,64
6,607	2,81
7,586	2,99
8,710	3,16
10,000	3,34
11,482	

Size (µm)	Volume In %
11,482	3,51
13,183	3,68
15,136	3,86
17,378	4,06
19,953	4,26
22,909	4,48
26,303	4,67
30,200	4,81
34,674	4,86
39,811	4,79
45,709	4,55
52,481	4,14
60,256	3,57
69,183	2,88
79,433	2,15
91,201	1,44
104,713	0,81
120,226	

Size (µm)	Volume In %
120,226	0,22
138,038	0,00
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.8 Particle size analysis result for “70T30 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

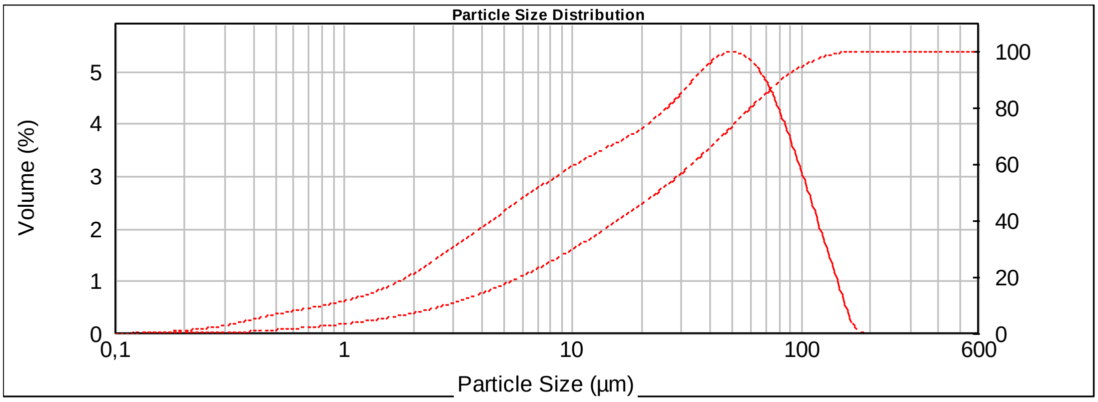
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,06
0,240	0,09
0,275	0,12
0,316	0,17
0,363	0,22
0,417	0,28
0,479	0,33
0,550	0,38
0,631	0,42
0,724	0,46
0,832	0,50
0,955	0,56
1,096	

Size (µm)	Volume In %
1,096	0,62
1,259	0,70
1,445	0,79
1,660	0,90
1,905	1,03
2,188	1,17
2,512	1,33
2,884	1,49
3,311	1,66
3,802	1,83
4,365	2,00
5,012	2,16
5,754	2,32
6,607	2,48
7,586	2,64
8,710	2,79
10,000	2,93
11,482	

Size (µm)	Volume In %
11,482	3,06
13,183	3,18
15,136	3,30
17,378	3,43
19,953	3,59
22,909	3,78
26,303	4,02
30,200	4,27
34,674	4,53
39,811	4,73
45,709	4,84
52,481	4,80
60,256	4,58
69,183	4,17
79,433	3,61
91,201	2,94
104,713	2,22
120,226	

Size (µm)	Volume In %
120,226	1,53
138,038	0,79
158,489	0,15
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.9 Particle size analysis result for “70T15L15 Interground”

Size (µm)	Volume In %
0,010	
	0,00
0,011	
	0,00
0,013	
	0,00
0,015	
	0,00
0,017	
	0,00
0,020	
	0,00
0,023	
	0,00
0,026	
	0,00
0,030	
	0,00
0,035	
	0,00
0,040	
	0,00
0,046	
	0,00
0,052	
	0,00
0,060	
	0,00
0,069	
	0,00
0,079	
	0,00
0,091	
	0,00
0,105	

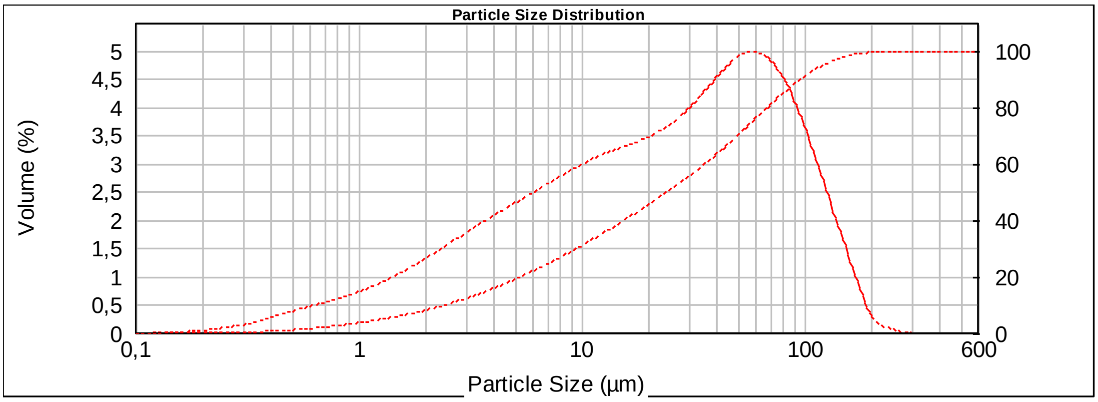
Size (µm)	Volume In %
0,105	
	0,00
0,120	
	0,00
0,138	
	0,01
0,158	
	0,02
0,182	
	0,04
0,209	
	0,06
0,240	
	0,09
0,275	
	0,13
0,316	
	0,17
0,363	
	0,23
0,417	
	0,30
0,479	
	0,36
0,550	
	0,41
0,631	
	0,47
0,724	
	0,53
0,832	
	0,60
0,955	
	0,67
1,096	

Size (µm)	Volume In %
1,096	
	0,76
1,259	
	0,85
1,445	
	0,96
1,660	
	1,08
1,905	
	1,21
2,188	
	1,34
2,512	
	1,48
2,884	
	1,62
3,311	
	1,75
3,802	
	1,88
4,365	
	2,01
5,012	
	2,13
5,754	
	2,26
6,607	
	2,38
7,586	
	2,51
8,710	
	2,63
10,000	
	2,74
11,482	

Size (µm)	Volume In %
11,482	
	2,84
13,183	
	2,93
15,136	
	3,00
17,378	
	3,08
19,953	
	3,18
22,909	
	3,31
26,303	
	3,49
30,200	
	3,70
34,674	
	3,94
39,811	
	4,18
45,709	
	4,38
52,481	
	4,49
60,256	
	4,46
69,183	
	4,26
79,433	
	3,89
91,201	
	3,39
104,713	
	2,78
120,226	

Size (µm)	Volume In %
120,226	
	2,14
138,038	
	1,50
158,489	
	0,89
181,970	
	0,33
208,930	
	0,12
239,883	
	0,05
275,423	
	0,00
316,228	
	0,00
363,078	
	0,00
416,869	
	0,00
478,630	
	0,00
549,541	
	0,00
630,957	
	0,00
724,436	
	0,00
831,764	
	0,00
954,993	
	0,00
1096,478	
	0,00
1258,925	

Size (µm)	Volume In %
1258,925	
	0,00
1445,440	
	0,00
1659,587	
	0,00
1905,461	
	0,00
2187,762	
	0,00
2511,886	
	0,00
2884,032	
	0,00
3311,311	
	0,00
3801,894	
	0,00
4365,158	
	0,00
5011,872	
	0,00
5754,399	
	0,00
6606,934	
	0,00
7585,776	
	0,00
8709,636	
	0,00
10000,000	



A.10 Particle size analysis result for “70T15S15 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

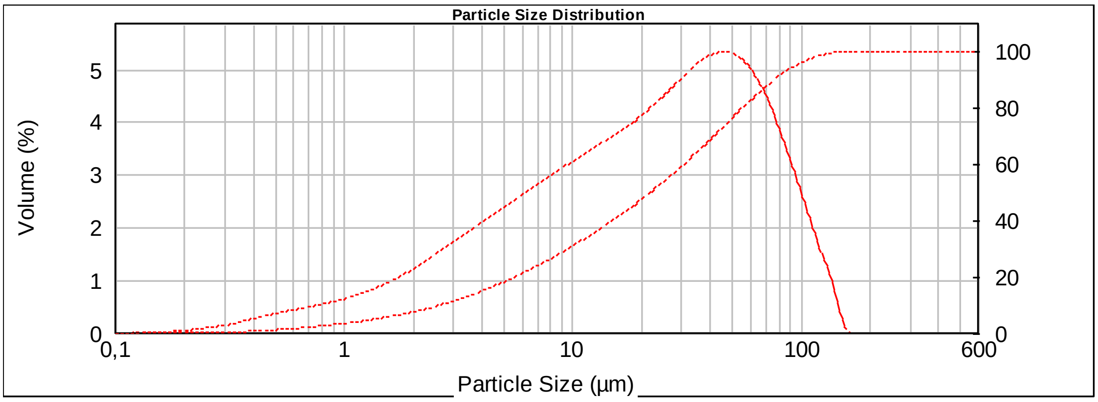
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,06
0,240	0,09
0,275	0,13
0,316	0,17
0,363	0,23
0,417	0,29
0,479	0,34
0,550	0,39
0,631	0,44
0,724	0,48
0,832	0,53
0,955	0,59
1,096	

Size (µm)	Volume In %
1,096	0,66
1,259	0,75
1,445	0,85
1,660	0,97
1,905	1,10
2,188	1,25
2,512	1,40
2,884	1,57
3,311	1,73
3,802	1,89
4,365	2,05
5,012	2,21
5,754	2,37
6,607	2,52
7,586	2,69
8,710	2,84
10,000	3,00
11,482	

Size (µm)	Volume In %
11,482	3,15
13,183	3,29
15,136	3,44
17,378	3,61
19,953	3,80
22,909	4,01
26,303	4,24
30,200	4,47
34,674	4,66
39,811	4,78
45,709	4,80
52,481	4,66
60,256	4,35
69,183	3,86
79,433	3,24
91,201	2,55
104,713	1,83
120,226	

Size (µm)	Volume In %
120,226	1,22
138,038	0,38
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.11 Particle size analysis result for “70L30 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

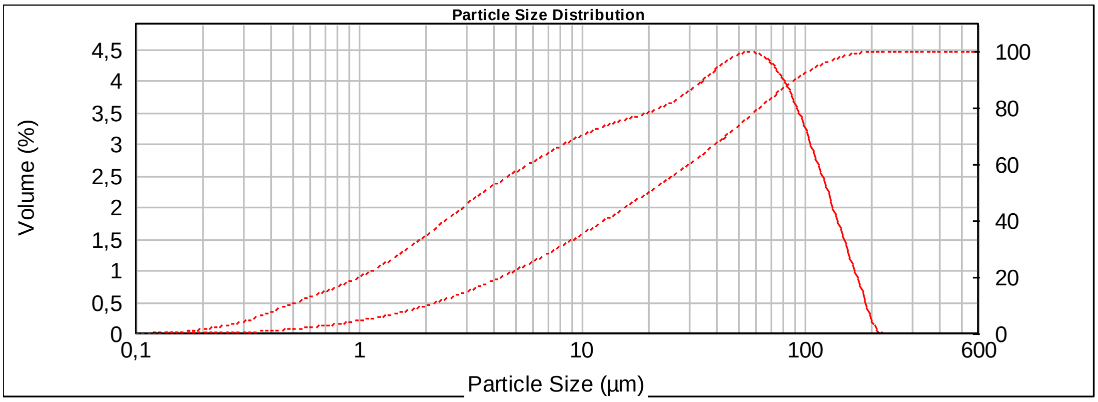
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,08
0,240	0,11
0,275	0,15
0,316	0,21
0,363	0,28
0,417	0,36
0,479	0,43
0,550	0,50
0,631	0,57
0,724	0,64
0,832	0,72
0,955	0,81
1,096	

Size (µm)	Volume In %
1,096	0,91
1,259	1,02
1,445	1,14
1,660	1,27
1,905	1,41
2,188	1,56
2,512	1,70
2,884	1,85
3,311	1,98
3,802	2,11
4,365	2,23
5,012	2,35
5,754	2,46
6,607	2,57
7,586	2,67
8,710	2,77
10,000	2,86
11,482	

Size (µm)	Volume In %
11,482	2,94
13,183	3,01
15,136	3,06
17,378	3,12
19,953	3,18
22,909	3,27
26,303	3,38
30,200	3,52
34,674	3,68
39,811	3,84
45,709	3,97
52,481	4,02
60,256	3,97
69,183	3,78
79,433	3,46
91,201	3,03
104,713	2,50
120,226	

Size (µm)	Volume In %
120,226	1,95
138,038	1,39
158,489	0,84
181,970	0,28
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.12 Particle size analysis result for “70L15S15 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

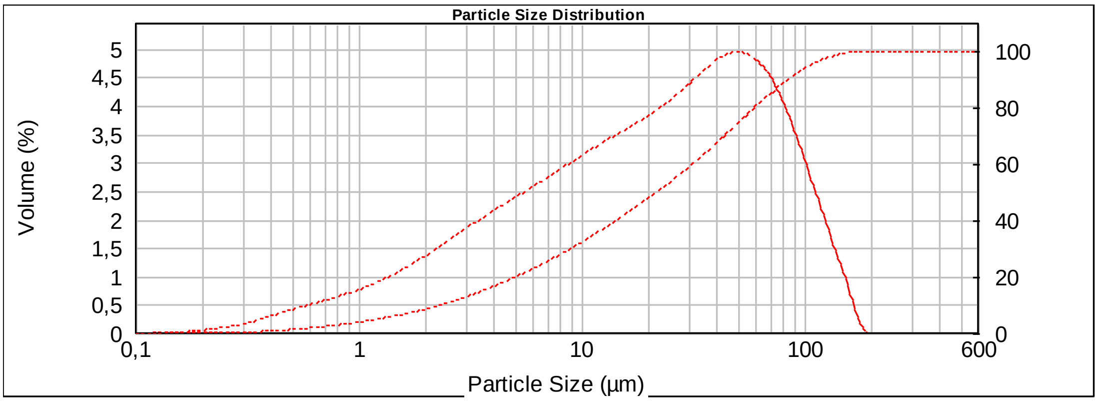
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,32
0,479	0,38
0,550	0,44
0,631	0,50
0,724	0,56
0,832	0,63
0,955	0,70
1,096	

Size (µm)	Volume In %
1,096	0,78
1,259	0,88
1,445	0,99
1,660	1,11
1,905	1,25
2,188	1,39
2,512	1,53
2,884	1,67
3,311	1,81
3,802	1,95
4,365	2,08
5,012	2,21
5,754	2,34
6,607	2,47
7,586	2,61
8,710	2,74
10,000	2,88
11,482	

Size (µm)	Volume In %
11,482	3,01
13,183	3,13
15,136	3,25
17,378	3,38
19,953	3,52
22,909	3,68
26,303	3,86
30,200	4,05
34,674	4,23
39,811	4,39
45,709	4,47
52,481	4,43
60,256	4,25
69,183	3,91
79,433	3,43
91,201	2,85
104,713	2,22
120,226	

Size (µm)	Volume In %
120,226	1,60
138,038	0,98
158,489	0,32
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.13 Particle size analysis result for “70S30 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

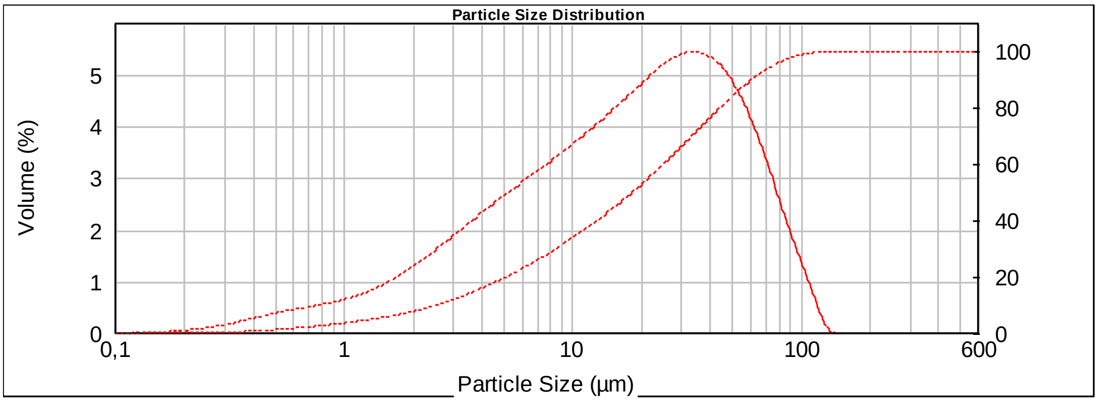
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,18
0,363	0,25
0,417	0,31
0,479	0,36
0,550	0,40
0,631	0,45
0,724	0,49
0,832	0,54
0,955	0,60
1,096	

Size (µm)	Volume In %
1,096	0,67
1,259	0,76
1,445	0,88
1,660	1,01
1,905	1,17
2,188	1,35
2,512	1,53
2,884	1,73
3,311	1,92
3,802	2,11
4,365	2,30
5,012	2,48
5,754	2,66
6,607	2,83
7,586	3,01
8,710	3,19
10,000	3,38
11,482	

Size (µm)	Volume In %
11,482	3,58
13,183	3,79
15,136	4,01
17,378	4,23
19,953	4,45
22,909	4,65
26,303	4,81
30,200	4,90
34,674	4,89
39,811	4,75
45,709	4,47
52,481	4,03
60,256	3,45
69,183	2,77
79,433	2,06
91,201	1,37
104,713	0,72
120,226	

Size (µm)	Volume In %
120,226	0,14
138,038	0,00
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.14 Particle size analysis result for “60T40 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

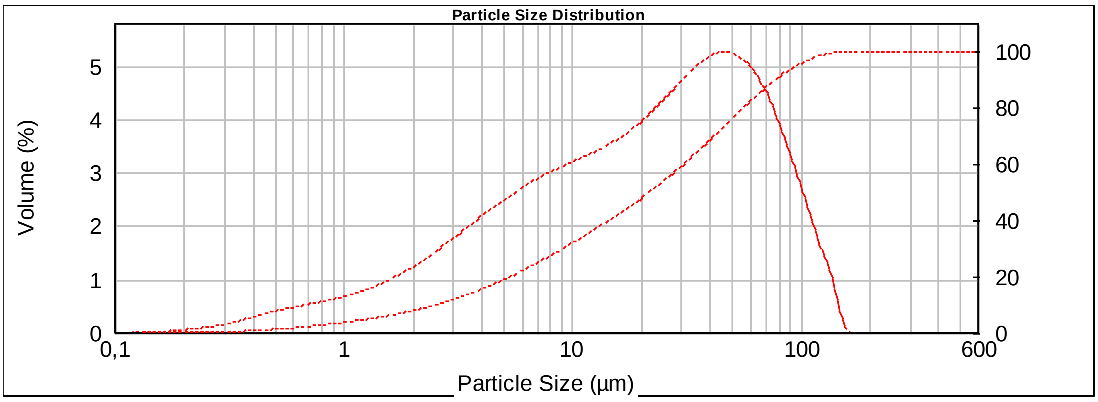
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,31
0,479	0,37
0,550	0,42
0,631	0,47
0,724	0,52
0,832	0,57
0,955	0,62
1,096	

Size (µm)	Volume In %
1,096	0,69
1,259	0,77
1,445	0,87
1,660	0,99
1,905	1,12
2,188	1,28
2,512	1,44
2,884	1,62
3,311	1,80
3,802	1,98
4,365	2,15
5,012	2,32
5,754	2,47
6,607	2,60
7,586	2,72
8,710	2,83
10,000	2,93
11,482	

Size (µm)	Volume In %
11,482	3,04
13,183	3,15
15,136	3,29
17,378	3,46
19,953	3,66
22,909	3,90
26,303	4,14
30,200	4,38
34,674	4,58
39,811	4,72
45,709	4,74
52,481	4,62
60,256	4,34
69,183	3,88
79,433	3,28
91,201	2,60
104,713	1,88
120,226	

Size (µm)	Volume In %
120,226	1,25
138,038	0,40
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.15 Particle size analysis result for “60T20L20 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

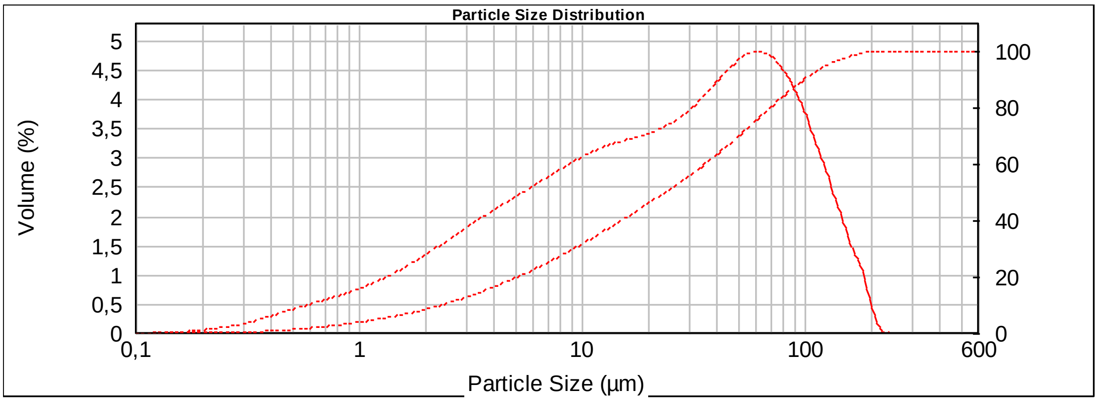
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,13
0,316	0,18
0,363	0,24
0,417	0,31
0,479	0,37
0,550	0,43
0,631	0,49
0,724	0,55
0,832	0,62
0,955	0,69
1,096	

Size (µm)	Volume In %
1,096	0,77
1,259	0,87
1,445	0,98
1,660	1,09
1,905	1,22
2,188	1,36
2,512	1,50
2,884	1,63
3,311	1,77
3,802	1,90
4,365	2,03
5,012	2,15
5,754	2,28
6,607	2,40
7,586	2,53
8,710	2,65
10,000	2,76
11,482	

Size (µm)	Volume In %
11,482	2,85
13,183	2,93
15,136	2,98
17,378	3,04
19,953	3,11
22,909	3,21
26,303	3,34
30,200	3,52
34,674	3,73
39,811	3,96
45,709	4,17
52,481	4,31
60,256	4,33
69,183	4,20
79,433	3,91
91,201	3,48
104,713	2,94
120,226	

Size (µm)	Volume In %
120,226	2,34
138,038	1,73
158,489	1,19
181,970	0,56
208,930	0,02
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.16 Particle size analysis result for “60T20S20 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

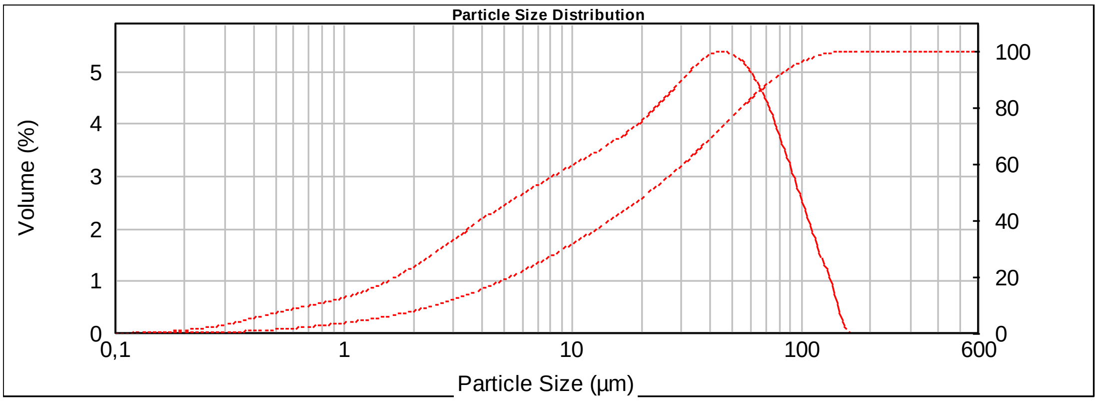
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,13
0,316	0,18
0,363	0,24
0,417	0,30
0,479	0,36
0,550	0,41
0,631	0,45
0,724	0,50
0,832	0,55
0,955	0,62
1,096	

Size (µm)	Volume In %
1,096	0,69
1,259	0,78
1,445	0,88
1,660	1,01
1,905	1,15
2,188	1,30
2,512	1,46
2,884	1,63
3,311	1,80
3,802	1,96
4,365	2,11
5,012	2,26
5,754	2,41
6,607	2,54
7,586	2,68
8,710	2,81
10,000	2,95
11,482	

Size (µm)	Volume In %
11,482	3,08
13,183	3,21
15,136	3,36
17,378	3,53
19,953	3,74
22,909	3,97
26,303	4,23
30,200	4,48
34,674	4,70
39,811	4,83
45,709	4,83
52,481	4,67
60,256	4,32
69,183	3,80
79,433	3,16
91,201	2,46
104,713	1,75
120,226	

Size (µm)	Volume In %
120,226	1,14
138,038	0,35
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.17 Particle size analysis result for “60L40 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

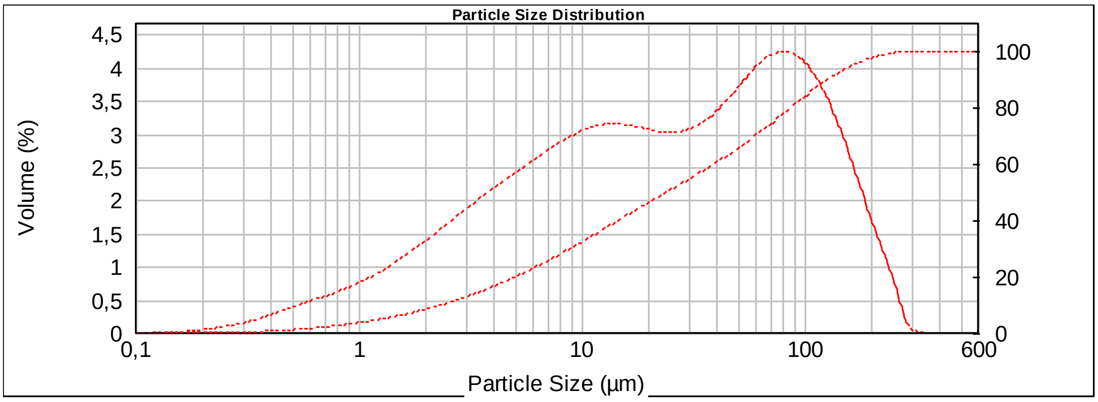
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,06
0,240	0,09
0,275	0,13
0,316	0,17
0,363	0,23
0,417	0,30
0,479	0,36
0,550	0,42
0,631	0,48
0,724	0,54
0,832	0,61
0,955	0,69
1,096	

Size (µm)	Volume In %
1,096	0,78
1,259	0,89
1,445	1,00
1,660	1,13
1,905	1,27
2,188	1,41
2,512	1,56
2,884	1,70
3,311	1,84
3,802	1,97
4,365	2,10
5,012	2,23
5,754	2,36
6,607	2,48
7,586	2,60
8,710	2,70
10,000	2,78
11,482	

Size (µm)	Volume In %
11,482	2,83
13,183	2,84
15,136	2,83
17,378	2,79
19,953	2,75
22,909	2,73
26,303	2,74
30,200	2,80
34,674	2,92
39,811	3,10
45,709	3,30
52,481	3,52
60,256	3,69
69,183	3,80
79,433	3,82
91,201	3,71
104,713	3,48
120,226	

Size (µm)	Volume In %
120,226	3,13
138,038	2,67
158,489	2,16
181,970	1,62
208,930	1,11
239,883	0,60
275,423	0,08
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.18 Particle size analysis result for “60L20S20 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

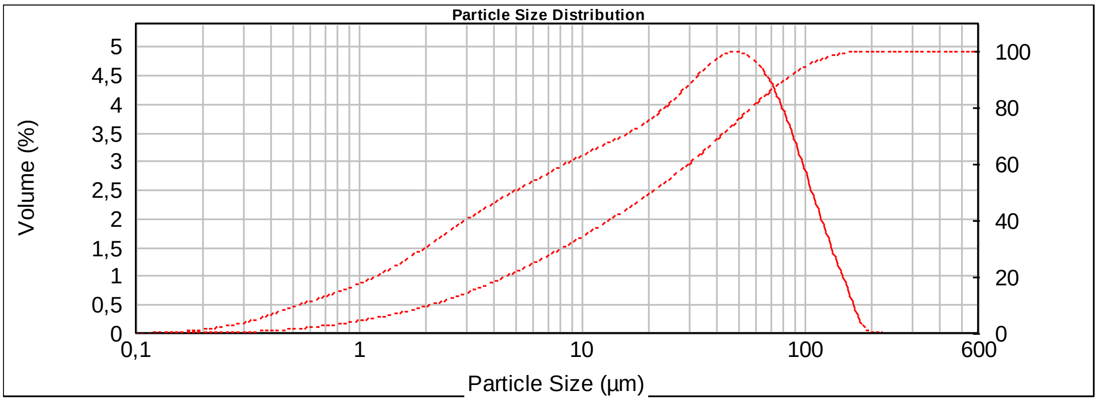
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,11
0,275	0,15
0,316	0,20
0,363	0,27
0,417	0,34
0,479	0,41
0,550	0,48
0,631	0,55
0,724	0,62
0,832	0,70
0,955	0,78
1,096	

Size (µm)	Volume In %
1,096	0,88
1,259	0,98
1,445	1,10
1,660	1,23
1,905	1,37
2,188	1,51
2,512	1,65
2,884	1,79
3,311	1,92
3,802	2,05
4,365	2,17
5,012	2,28
5,754	2,40
6,607	2,51
7,586	2,62
8,710	2,73
10,000	2,84
11,482	

Size (µm)	Volume In %
11,482	2,94
13,183	3,04
15,136	3,14
17,378	3,27
19,953	3,42
22,909	3,60
26,303	3,80
30,200	4,01
34,674	4,21
39,811	4,36
45,709	4,43
52,481	4,37
60,256	4,15
69,183	3,78
79,433	3,27
91,201	2,67
104,713	2,04
120,226	

Size (µm)	Volume In %
120,226	1,44
138,038	0,89
158,489	0,34
181,970	0,04
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.19 Particle size analysis result for “60S40 Interground”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

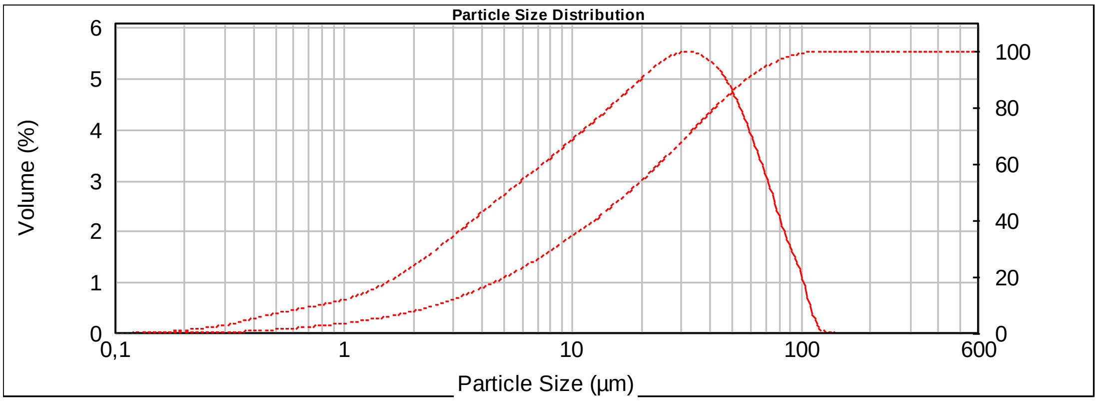
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,13
0,316	0,18
0,363	0,24
0,417	0,30
0,479	0,35
0,550	0,40
0,631	0,44
0,724	0,49
0,832	0,54
0,955	0,60
1,096	

Size (µm)	Volume In %
1,096	0,68
1,259	0,77
1,445	0,89
1,660	1,02
1,905	1,18
2,188	1,36
2,512	1,55
2,884	1,74
3,311	1,94
3,802	2,14
4,365	2,34
5,012	2,53
5,754	2,72
6,607	2,91
7,586	3,11
8,710	3,31
10,000	3,52
11,482	

Size (µm)	Volume In %
11,482	3,72
13,183	3,94
15,136	4,15
17,378	4,38
19,953	4,59
22,909	4,78
26,303	4,92
30,200	4,98
34,674	4,92
39,811	4,72
45,709	4,36
52,481	3,85
60,256	3,21
69,183	2,51
79,433	1,78
91,201	1,18
104,713	0,34
120,226	

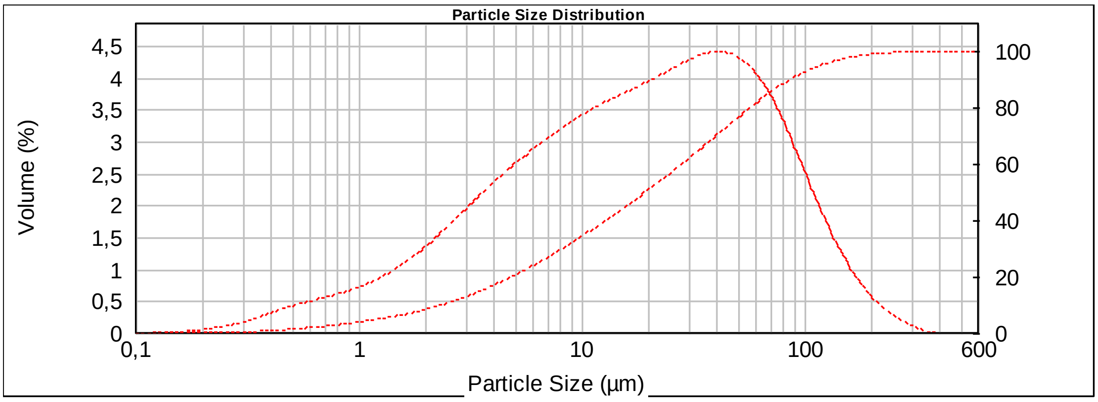
Size (µm)	Volume In %
120,226	0,03
138,038	0,00
158,489	0,00
181,970	0,00
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.20 Particle size analysis result for “80T20 Separate Grinding”

Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0,010	0,00	0,105	0,00	1,096	0,74	11,482	3,24	120,226	1,48	1258,925	0,00
0,011	0,00	0,120	0,00	1,259	0,84	13,183	3,33	138,038	1,10	1445,440	0,00
0,013	0,00	0,138	0,01	1,445	0,95	15,136	3,42	158,489	0,80	1659,587	0,00
0,015	0,00	0,158	0,03	1,660	1,09	17,378	3,51	181,970	0,55	1905,461	0,00
0,017	0,00	0,182	0,05	1,905	1,25	19,953	3,60	208,930	0,37	2187,762	0,00
0,020	0,00	0,209	0,07	2,188	1,42	22,909	3,71	239,883	0,23	2511,886	0,00
0,023	0,00	0,240	0,11	2,512	1,60	26,303	3,81	275,423	0,13	2884,032	0,00
0,026	0,00	0,275	0,14	2,884	1,79	30,200	3,90	316,228	0,04	3311,311	0,00
0,030	0,00	0,316	0,20	3,311	1,97	34,674	3,96	363,078	0,00	3801,894	0,00
0,035	0,00	0,363	0,26	3,802	2,14	39,811	3,98	416,869	0,00	4365,158	0,00
0,040	0,00	0,417	0,33	4,365	2,31	45,709	3,93	478,630	0,00	5011,872	0,00
0,046	0,00	0,479	0,39	5,012	2,47	52,481	3,79	549,541	0,00	5754,399	0,00
0,052	0,00	0,550	0,44	5,754	2,62	60,256	3,55	630,957	0,00	6606,934	0,00
0,060	0,00	0,631	0,49	6,607	2,76	69,183	3,22	724,436	0,00	7585,776	0,00
0,069	0,00	0,724	0,54	7,586	2,89	79,433	2,80	831,764	0,00	8709,636	0,00
0,079	0,00	0,832	0,59	8,710	3,02	91,201	2,36	954,993	0,00	10000,000	
0,091	0,00	0,955	0,66	10,000	3,14	104,713	1,90	1096,478	0,00		
0,105		1,096		11,482		120,226		1258,925			



A.21 Particle size analysis result for “80T10L10 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

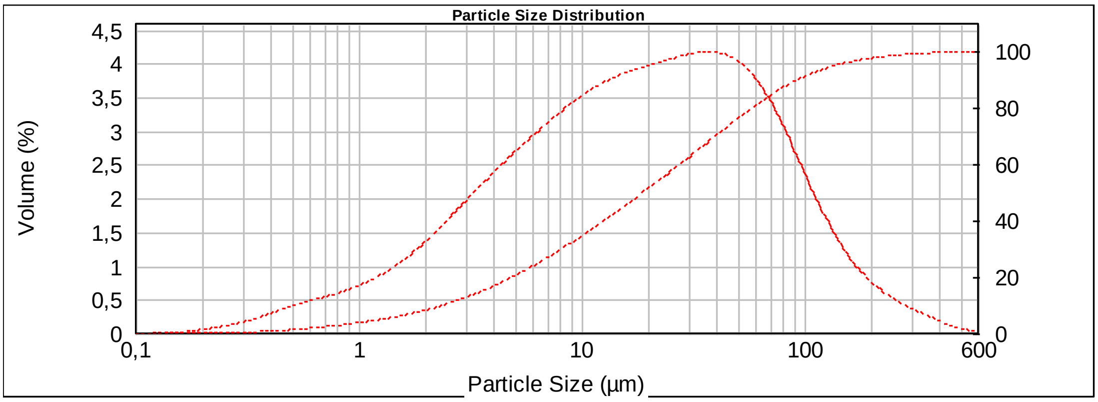
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,32
0,479	0,37
0,550	0,43
0,631	0,47
0,724	0,52
0,832	0,58
0,955	0,65
1,096	

Size (µm)	Volume In %
1,096	0,73
1,259	0,83
1,445	0,95
1,660	1,09
1,905	1,25
2,188	1,43
2,512	1,61
2,884	1,80
3,311	1,99
3,802	2,17
4,365	2,34
5,012	2,51
5,754	2,67
6,607	2,82
7,586	2,97
8,710	3,10
10,000	3,23
11,482	

Size (µm)	Volume In %
11,482	3,34
13,183	3,42
15,136	3,49
17,378	3,55
19,953	3,61
22,909	3,66
26,303	3,71
30,200	3,75
34,674	3,76
39,811	3,75
45,709	3,67
52,481	3,52
60,256	3,28
69,183	2,97
79,433	2,60
91,201	2,20
104,713	1,81
120,226	

Size (µm)	Volume In %
120,226	1,46
138,038	1,15
158,489	0,91
181,970	0,71
208,930	0,57
239,883	0,45
275,423	0,35
316,228	0,27
363,078	0,19
416,869	0,11
478,630	0,06
549,541	0,02
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.22 Particle size analysis result for “80T10S10 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

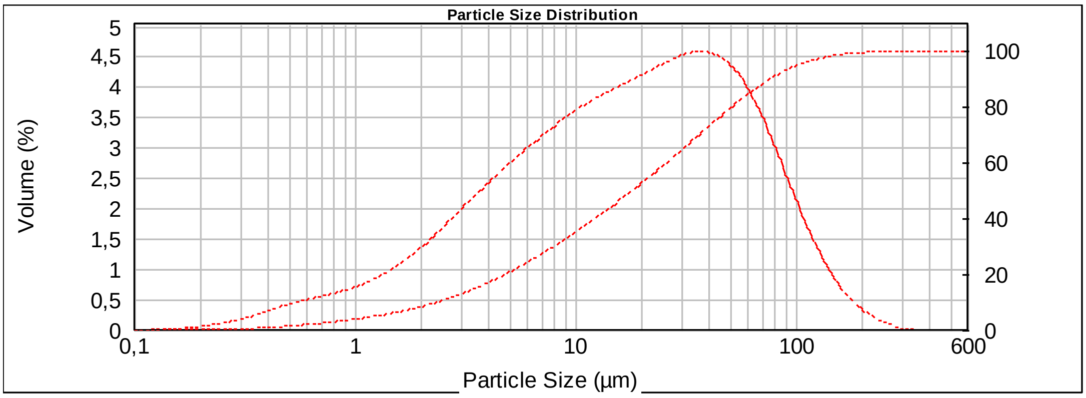
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,08
0,240	0,11
0,275	0,15
0,316	0,20
0,363	0,26
0,417	0,33
0,479	0,39
0,550	0,44
0,631	0,48
0,724	0,53
0,832	0,58
0,955	0,64
1,096	

Size (µm)	Volume In %
1,096	0,72
1,259	0,82
1,445	0,94
1,660	1,09
1,905	1,25
2,188	1,43
2,512	1,62
2,884	1,82
3,311	2,01
3,802	2,20
4,365	2,38
5,012	2,55
5,754	2,72
6,607	2,88
7,586	3,04
8,710	3,18
10,000	3,31
11,482	

Size (µm)	Volume In %
11,482	3,43
13,183	3,54
15,136	3,63
17,378	3,73
19,953	3,83
22,909	3,93
26,303	4,03
30,200	4,10
34,674	4,14
39,811	4,10
45,709	3,98
52,481	3,75
60,256	3,41
69,183	2,99
79,433	2,50
91,201	2,01
104,713	1,54
120,226	

Size (µm)	Volume In %
120,226	1,13
138,038	0,78
158,489	0,52
181,970	0,33
208,930	0,20
239,883	0,11
275,423	0,03
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.23 Particle size analysis result for “80L20 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

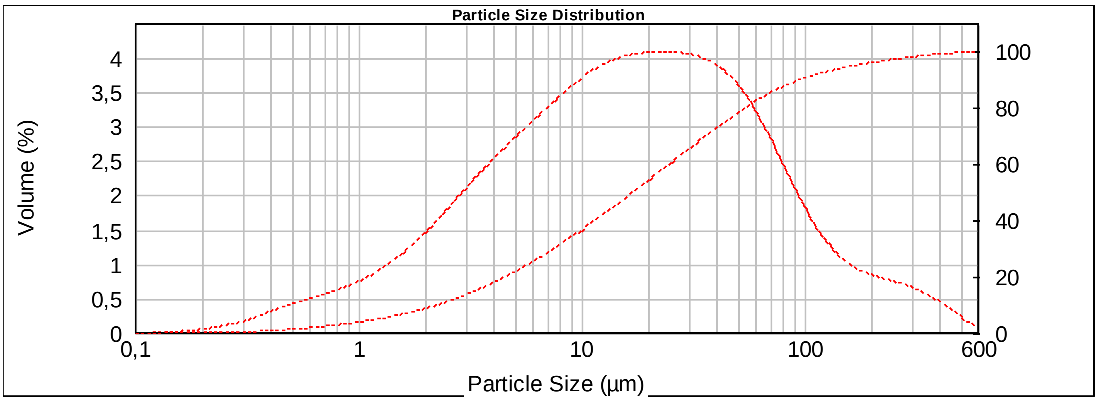
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,11
0,275	0,14
0,316	0,20
0,363	0,26
0,417	0,33
0,479	0,39
0,550	0,44
0,631	0,49
0,724	0,55
0,832	0,61
0,955	0,68
1,096	

Size (µm)	Volume In %
1,096	0,78
1,259	0,89
1,445	1,02
1,660	1,18
1,905	1,35
2,188	1,54
2,512	1,73
2,884	1,93
3,311	2,12
3,802	2,30
4,365	2,47
5,012	2,64
5,754	2,80
6,607	2,96
7,586	3,12
8,710	3,27
10,000	3,40
11,482	

Size (µm)	Volume In %
11,482	3,51
13,183	3,59
15,136	3,64
17,378	3,67
19,953	3,68
22,909	3,68
26,303	3,67
30,200	3,64
34,674	3,58
39,811	3,46
45,709	3,29
52,481	3,06
60,256	2,75
69,183	2,41
79,433	2,04
91,201	1,70
104,713	1,40
120,226	

Size (µm)	Volume In %
120,226	1,16
138,038	0,98
158,489	0,85
181,970	0,78
208,930	0,72
239,883	0,67
275,423	0,62
316,228	0,54
363,078	0,45
416,869	0,34
478,630	0,19
549,541	0,08
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.24 Particle size analysis result for “80L10S10 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

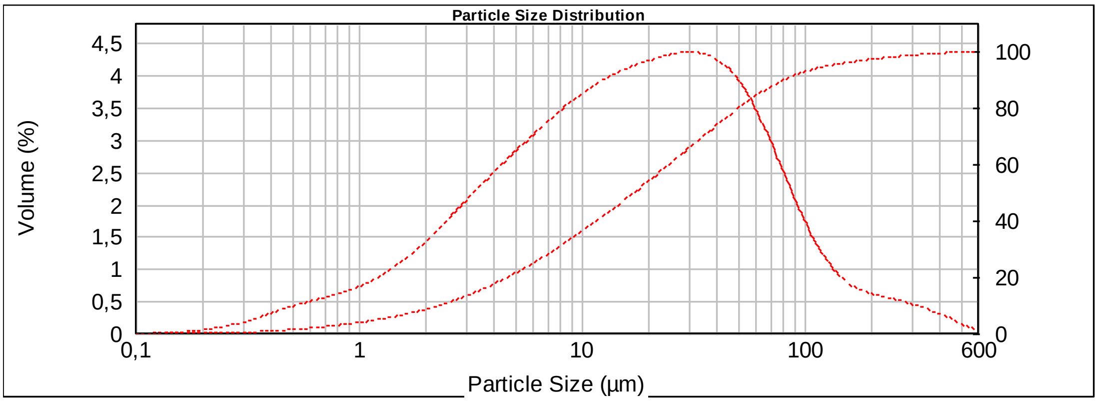
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,11
0,275	0,14
0,316	0,19
0,363	0,26
0,417	0,32
0,479	0,38
0,550	0,43
0,631	0,48
0,724	0,53
0,832	0,59
0,955	0,66
1,096	

Size (µm)	Volume In %
1,096	0,75
1,259	0,86
1,445	0,99
1,660	1,14
1,905	1,31
2,188	1,49
2,512	1,69
2,884	1,88
3,311	2,08
3,802	2,27
4,365	2,45
5,012	2,63
5,754	2,80
6,607	2,96
7,586	3,12
8,710	3,27
10,000	3,41
11,482	

Size (µm)	Volume In %
11,482	3,53
13,183	3,62
15,136	3,71
17,378	3,78
19,953	3,84
22,909	3,89
26,303	3,93
30,200	3,93
34,674	3,89
39,811	3,78
45,709	3,59
52,481	3,31
60,256	2,94
69,183	2,51
79,433	2,06
91,201	1,63
104,713	1,26
120,226	

Size (µm)	Volume In %
120,226	0,98
138,038	0,77
158,489	0,64
181,970	0,57
208,930	0,52
239,883	0,47
275,423	0,43
316,228	0,36
363,078	0,29
416,869	0,22
478,630	0,12
549,541	0,05
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.25 Particle size analysis result for “80S20 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

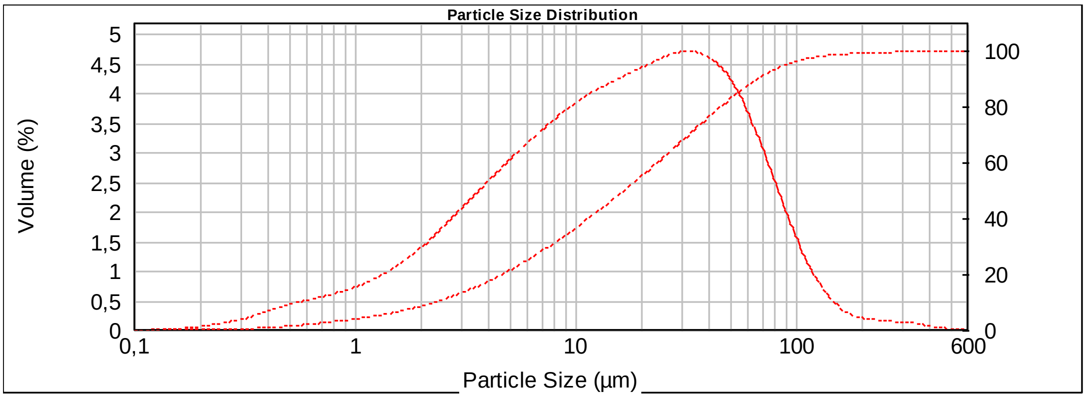
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,08
0,240	0,11
0,275	0,15
0,316	0,20
0,363	0,27
0,417	0,33
0,479	0,39
0,550	0,44
0,631	0,49
0,724	0,54
0,832	0,59
0,955	0,66
1,096	

Size (µm)	Volume In %
1,096	0,74
1,259	0,85
1,445	0,97
1,660	1,12
1,905	1,29
2,188	1,47
2,512	1,67
2,884	1,88
3,311	2,09
3,802	2,29
4,365	2,49
5,012	2,68
5,754	2,87
6,607	3,05
7,586	3,22
8,710	3,38
10,000	3,52
11,482	

Size (µm)	Volume In %
11,482	3,64
13,183	3,75
15,136	3,85
17,378	3,95
19,953	4,05
22,909	4,14
26,303	4,22
30,200	4,25
34,674	4,22
39,811	4,11
45,709	3,88
52,481	3,54
60,256	3,09
69,183	2,57
79,433	2,02
91,201	1,50
104,713	1,04
120,226	

Size (µm)	Volume In %
120,226	0,68
138,038	0,43
158,489	0,28
181,970	0,20
208,930	0,16
239,883	0,14
275,423	0,12
316,228	0,11
363,078	0,07
416,869	0,04
478,630	0,02
549,541	0,01
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.26 Particle size analysis result for “70T30 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

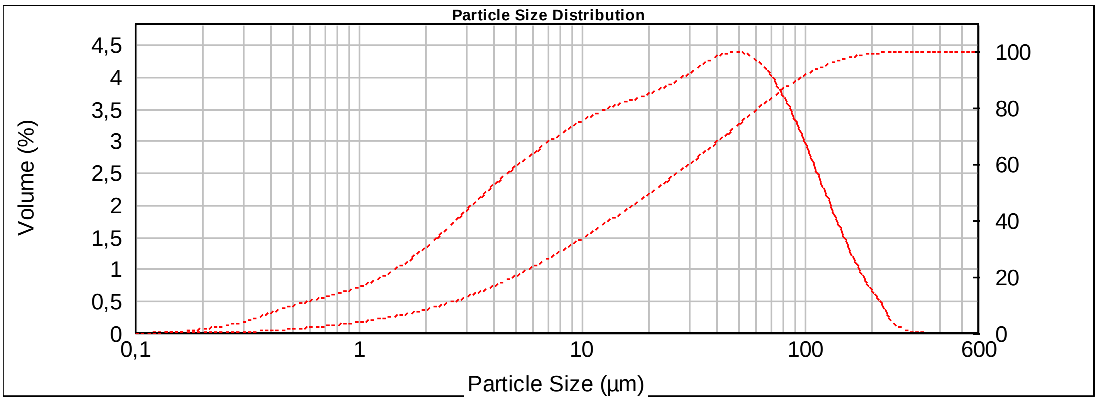
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,11
0,275	0,15
0,316	0,20
0,363	0,26
0,417	0,33
0,479	0,39
0,550	0,44
0,631	0,49
0,724	0,54
0,832	0,59
0,955	0,65
1,096	

Size (µm)	Volume In %
1,096	0,73
1,259	0,83
1,445	0,94
1,660	1,07
1,905	1,22
2,188	1,39
2,512	1,57
2,884	1,74
3,311	1,92
3,802	2,09
4,365	2,25
5,012	2,40
5,754	2,54
6,607	2,68
7,586	2,80
8,710	2,92
10,000	3,03
11,482	

Size (µm)	Volume In %
11,482	3,12
13,183	3,20
15,136	3,26
17,378	3,32
19,953	3,39
22,909	3,48
26,303	3,59
30,200	3,71
34,674	3,82
39,811	3,92
45,709	3,96
52,481	3,91
60,256	3,77
69,183	3,52
79,433	3,17
91,201	2,76
104,713	2,30
120,226	

Size (µm)	Volume In %
120,226	1,83
138,038	1,38
158,489	0,98
181,970	0,65
208,930	0,38
239,883	0,11
275,423	0,03
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.27 Particle size analysis result for “70T15L15 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

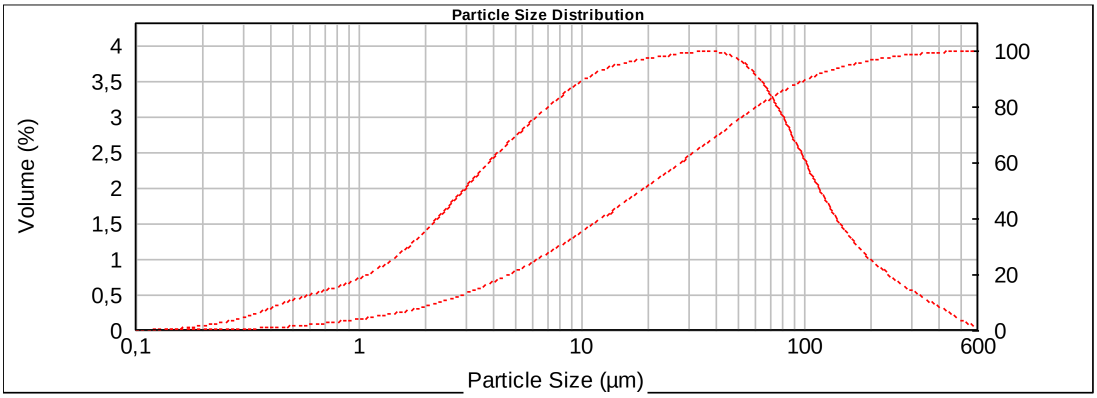
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,11
0,275	0,14
0,316	0,19
0,363	0,26
0,417	0,32
0,479	0,38
0,550	0,43
0,631	0,48
0,724	0,53
0,832	0,59
0,955	0,66
1,096	

Size (µm)	Volume In %
1,096	0,74
1,259	0,85
1,445	0,97
1,660	1,12
1,905	1,28
2,188	1,46
2,512	1,65
2,884	1,83
3,311	2,02
3,802	2,20
4,365	2,36
5,012	2,52
5,754	2,68
6,607	2,82
7,586	2,96
8,710	3,09
10,000	3,20
11,482	

Size (µm)	Volume In %
11,482	3,28
13,183	3,35
15,136	3,40
17,378	3,43
19,953	3,45
22,909	3,48
26,303	3,50
30,200	3,53
34,674	3,54
39,811	3,52
45,709	3,46
52,481	3,34
60,256	3,14
69,183	2,88
79,433	2,56
91,201	2,22
104,713	1,88
120,226	

Size (µm)	Volume In %
120,226	1,58
138,038	1,32
158,489	1,10
181,970	0,92
208,930	0,77
239,883	0,65
275,423	0,53
316,228	0,43
363,078	0,32
416,869	0,24
478,630	0,12
549,541	0,05
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.28 Particle size analysis result for “70T15S15 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

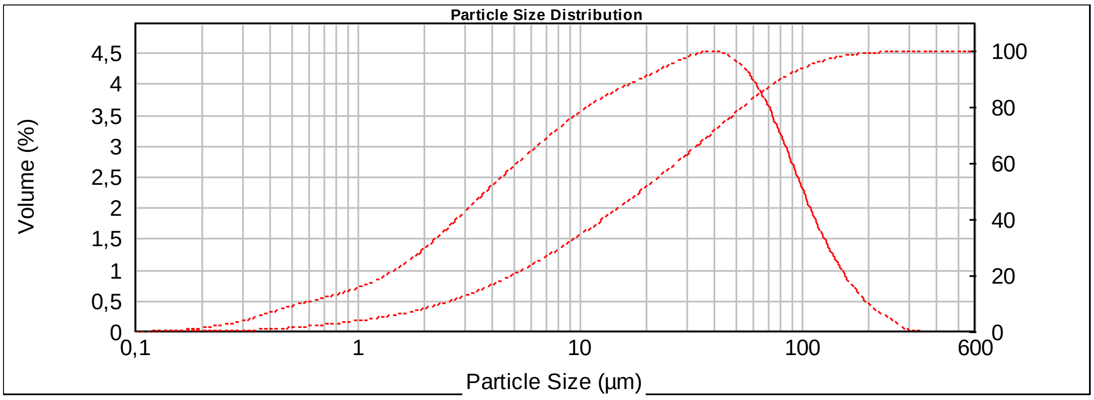
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,32
0,479	0,37
0,550	0,43
0,631	0,47
0,724	0,52
0,832	0,58
0,955	0,64
1,096	

Size (µm)	Volume In %
1,096	0,72
1,259	0,82
1,445	0,93
1,660	1,07
1,905	1,23
2,188	1,40
2,512	1,58
2,884	1,77
3,311	1,95
3,802	2,13
4,365	2,31
5,012	2,48
5,754	2,65
6,607	2,81
7,586	2,97
8,710	3,12
10,000	3,25
11,482	

Size (µm)	Volume In %
11,482	3,38
13,183	3,49
15,136	3,58
17,378	3,67
19,953	3,76
22,909	3,86
26,303	3,95
30,200	4,03
34,674	4,08
39,811	4,07
45,709	3,99
52,481	3,81
60,256	3,52
69,183	3,12
79,433	2,66
91,201	2,17
104,713	1,70
120,226	

Size (µm)	Volume In %
120,226	1,29
138,038	0,94
158,489	0,66
181,970	0,44
208,930	0,28
239,883	0,16
275,423	0,04
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.29 Particle size analysis result for “70L30 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

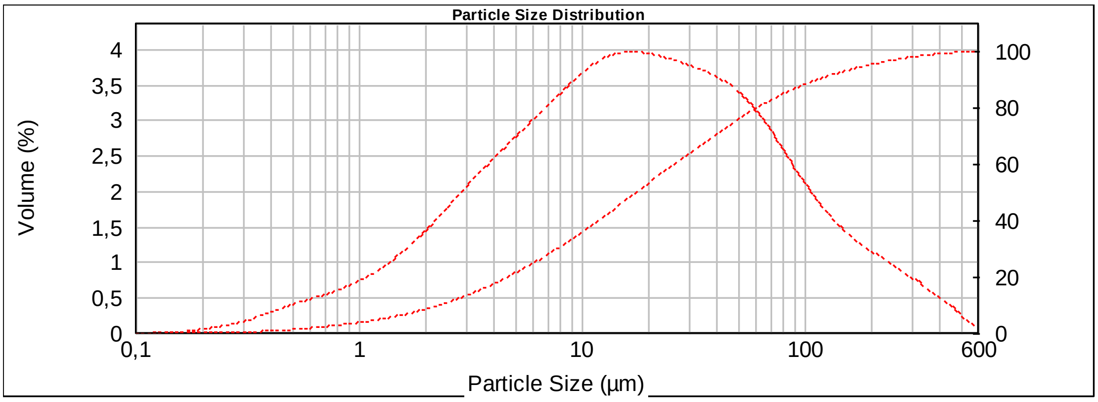
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,04
0,209	0,07
0,240	0,10
0,275	0,13
0,316	0,18
0,363	0,24
0,417	0,31
0,479	0,36
0,550	0,42
0,631	0,47
0,724	0,53
0,832	0,59
0,955	0,67
1,096	

Size (µm)	Volume In %
1,096	0,76
1,259	0,88
1,445	1,01
1,660	1,16
1,905	1,33
2,188	1,51
2,512	1,70
2,884	1,88
3,311	2,06
3,802	2,24
4,365	2,40
5,012	2,57
5,754	2,73
6,607	2,90
7,586	3,06
8,710	3,22
10,000	3,36
11,482	

Size (µm)	Volume In %
11,482	3,47
13,183	3,55
15,136	3,58
17,378	3,57
19,953	3,54
22,909	3,49
26,303	3,44
30,200	3,38
34,674	3,31
39,811	3,23
45,709	3,10
52,481	2,94
60,256	2,73
69,183	2,48
79,433	2,21
91,201	1,95
104,713	1,71
120,226	

Size (µm)	Volume In %
120,226	1,50
138,038	1,33
158,489	1,19
181,970	1,07
208,930	0,96
239,883	0,85
275,423	0,73
316,228	0,62
363,078	0,49
416,869	0,37
478,630	0,20
549,541	0,08
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.30 Particle size analysis result for “70L15S15 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

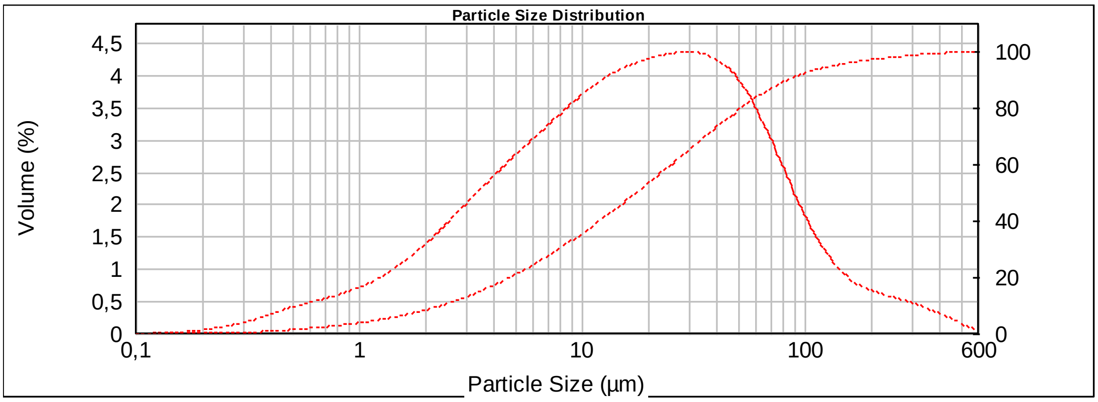
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,32
0,479	0,37
0,550	0,42
0,631	0,47
0,724	0,52
0,832	0,58
0,955	0,65
1,096	

Size (µm)	Volume In %
1,096	0,73
1,259	0,84
1,445	0,96
1,660	1,11
1,905	1,28
2,188	1,46
2,512	1,65
2,884	1,84
3,311	2,03
3,802	2,21
4,365	2,39
5,012	2,57
5,754	2,74
6,607	2,91
7,586	3,08
8,710	3,24
10,000	3,40
11,482	

Size (µm)	Volume In %
11,482	3,53
13,183	3,64
15,136	3,73
17,378	3,80
19,953	3,85
22,909	3,90
26,303	3,93
30,200	3,92
34,674	3,88
39,811	3,78
45,709	3,59
52,481	3,32
60,256	2,97
69,183	2,55
79,433	2,12
91,201	1,71
104,713	1,35
120,226	

Size (µm)	Volume In %
120,226	1,06
138,038	0,85
158,489	0,71
181,970	0,61
208,930	0,55
239,883	0,50
275,423	0,44
316,228	0,38
363,078	0,30
416,869	0,23
478,630	0,13
549,541	0,05
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.31 Particle size analysis result for “70S30 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

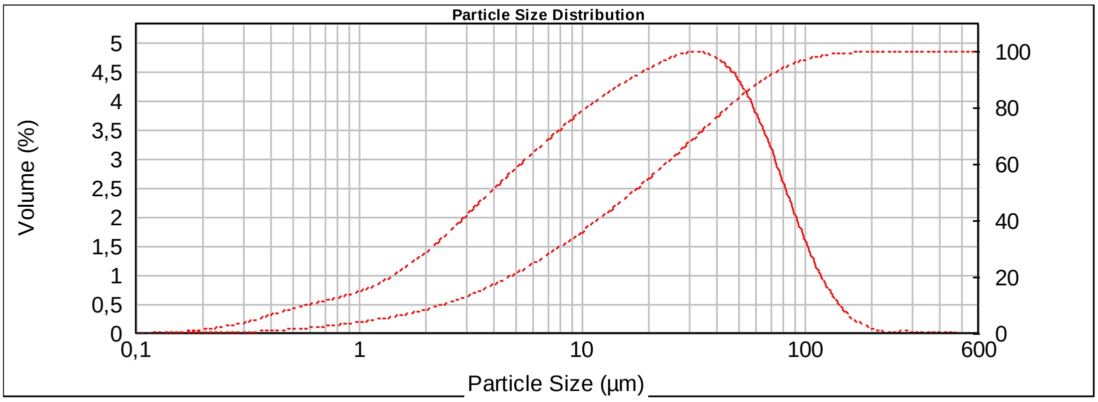
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,11
0,275	0,14
0,316	0,20
0,363	0,26
0,417	0,33
0,479	0,38
0,550	0,43
0,631	0,48
0,724	0,53
0,832	0,59
0,955	0,65
1,096	

Size (µm)	Volume In %
1,096	0,73
1,259	0,84
1,445	0,96
1,660	1,11
1,905	1,27
2,188	1,45
2,512	1,65
2,884	1,85
3,311	2,05
3,802	2,25
4,365	2,44
5,012	2,63
5,754	2,82
6,607	3,00
7,586	3,18
8,710	3,35
10,000	3,51
11,482	

Size (µm)	Volume In %
11,482	3,66
13,183	3,80
15,136	3,92
17,378	4,04
19,953	4,15
22,909	4,25
26,303	4,33
30,200	4,36
34,674	4,33
39,811	4,21
45,709	3,99
52,481	3,64
60,256	3,19
69,183	2,65
79,433	2,08
91,201	1,53
104,713	1,04
120,226	

Size (µm)	Volume In %
120,226	0,66
138,038	0,37
158,489	0,20
181,970	0,10
208,930	0,03
239,883	0,03
275,423	0,03
316,228	0,02
363,078	0,02
416,869	0,01
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.32 Particle size analysis result for “60T40 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

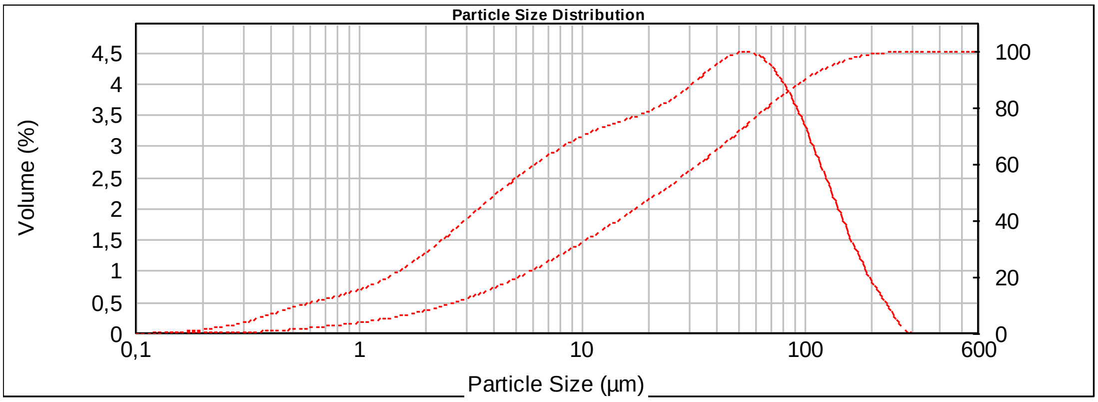
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,32
0,479	0,37
0,550	0,43
0,631	0,47
0,724	0,52
0,832	0,57
0,955	0,64
1,096	

Size (µm)	Volume In %
1,096	0,71
1,259	0,80
1,445	0,91
1,660	1,03
1,905	1,18
2,188	1,33
2,512	1,50
2,884	1,66
3,311	1,83
3,802	1,99
4,365	2,14
5,012	2,29
5,754	2,43
6,607	2,56
7,586	2,68
8,710	2,79
10,000	2,88
11,482	

Size (µm)	Volume In %
11,482	2,96
13,183	3,03
15,136	3,09
17,378	3,16
19,953	3,24
22,909	3,35
26,303	3,48
30,200	3,63
34,674	3,79
39,811	3,94
45,709	4,04
52,481	4,06
60,256	3,98
69,183	3,78
79,433	3,47
91,201	3,07
104,713	2,61
120,226	

Size (µm)	Volume In %
120,226	2,12
138,038	1,64
158,489	1,20
181,970	0,81
208,930	0,50
239,883	0,21
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.33 Particle size analysis result for “60T20L20 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

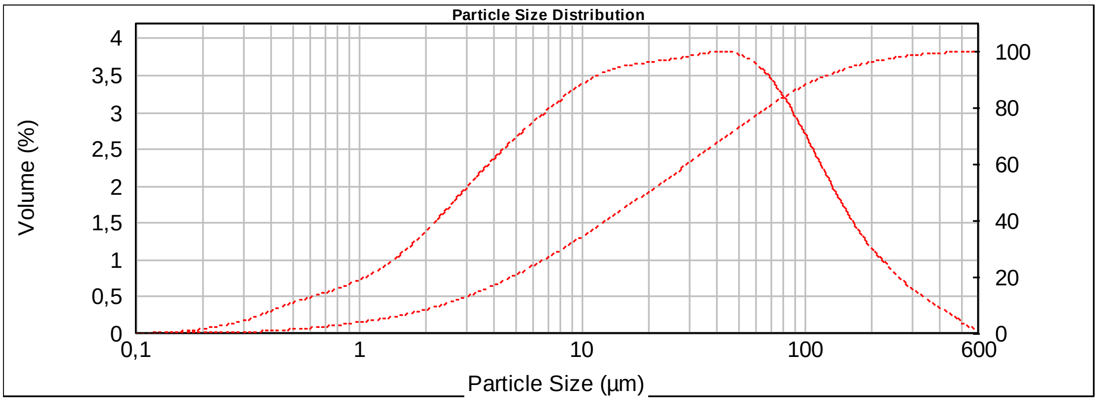
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,31
0,479	0,37
0,550	0,42
0,631	0,47
0,724	0,53
0,832	0,59
0,955	0,66
1,096	

Size (µm)	Volume In %
1,096	0,74
1,259	0,84
1,445	0,97
1,660	1,11
1,905	1,27
2,188	1,44
2,512	1,62
2,884	1,80
3,311	1,98
3,802	2,14
4,365	2,30
5,012	2,45
5,754	2,60
6,607	2,73
7,586	2,86
8,710	2,98
10,000	3,09
11,482	

Size (µm)	Volume In %
11,482	3,17
13,183	3,23
15,136	3,27
17,378	3,30
19,953	3,32
22,909	3,34
26,303	3,37
30,200	3,40
34,674	3,42
39,811	3,44
45,709	3,42
52,481	3,36
60,256	3,23
69,183	3,03
79,433	2,78
91,201	2,49
104,713	2,17
120,226	

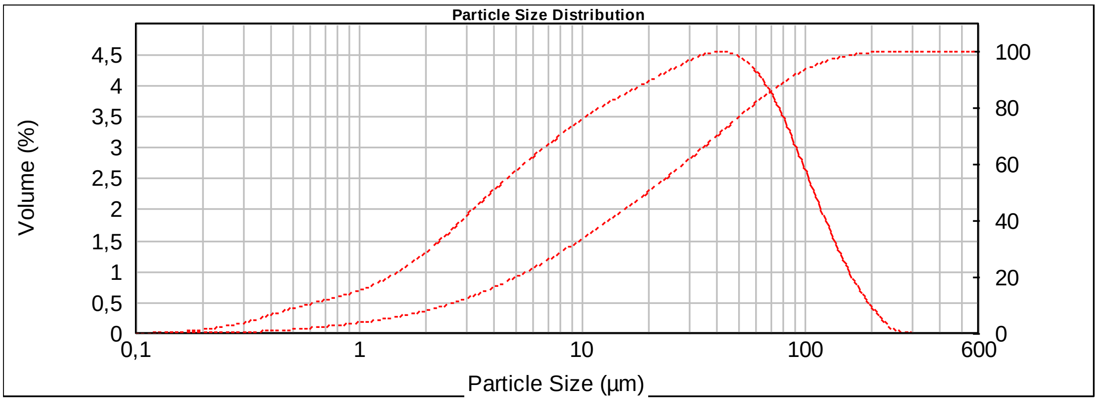
Size (µm)	Volume In %
120,226	1,86
138,038	1,56
158,489	1,30
181,970	1,07
208,930	0,88
239,883	0,72
275,423	0,58
316,228	0,45
363,078	0,34
416,869	0,24
478,630	0,12
549,541	0,04
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.34 Particle size analysis result for “60T20S20 Separate Grinding”

Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %	Size (µm)	Volume In %
0,010	0,00	0,105	0,00	1,096	0,70	11,482	3,28	120,226	1,51	1258,925	0,00
0,011	0,00	0,120	0,00	1,259	0,79	13,183	3,40	138,038	1,08	1445,440	0,00
0,013	0,00	0,138	0,01	1,445	0,91	15,136	3,50	158,489	0,72	1659,587	0,00
0,015	0,00	0,158	0,03	1,660	1,04	17,378	3,60	181,970	0,43	1905,461	0,00
0,017	0,00	0,182	0,04	1,905	1,19	19,953	3,70	208,930	0,19	2187,762	0,00
0,020	0,00	0,209	0,07	2,188	1,36	22,909	3,80	239,883	0,04	2511,886	0,00
0,023	0,00	0,240	0,10	2,512	1,54	26,303	3,90	275,423	0,00	2884,032	0,00
0,026	0,00	0,275	0,13	2,884	1,72	30,200	3,99	316,228	0,00	3311,311	0,00
0,030	0,00	0,316	0,18	3,311	1,90	34,674	4,06	363,078	0,00	3801,894	0,00
0,035	0,00	0,363	0,24	3,802	2,08	39,811	4,09	416,869	0,00	4365,158	0,00
0,040	0,00	0,417	0,31	4,365	2,26	45,709	4,05	478,630	0,00	5011,872	0,00
0,046	0,00	0,479	0,36	5,012	2,42	52,481	3,92	549,541	0,00	5754,399	0,00
0,052	0,00	0,550	0,41	5,754	2,58	60,256	3,68	630,957	0,00	6606,934	0,00
0,060	0,00	0,631	0,46	6,607	2,73	69,183	3,35	724,436	0,00	7585,776	0,00
0,069	0,00	0,724	0,51	7,586	2,88	79,433	2,93	831,764	0,00	8709,636	0,00
0,079	0,00	0,832	0,56	8,710	3,02	91,201	2,47	954,993	0,00	10000,000	
0,091	0,00	0,955	0,62	10,000	3,16	104,713	1,98	1096,478	0,00		
0,105		1,096		11,482		120,226		1258,925			



A.35 Particle size analysis result for “60L40 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

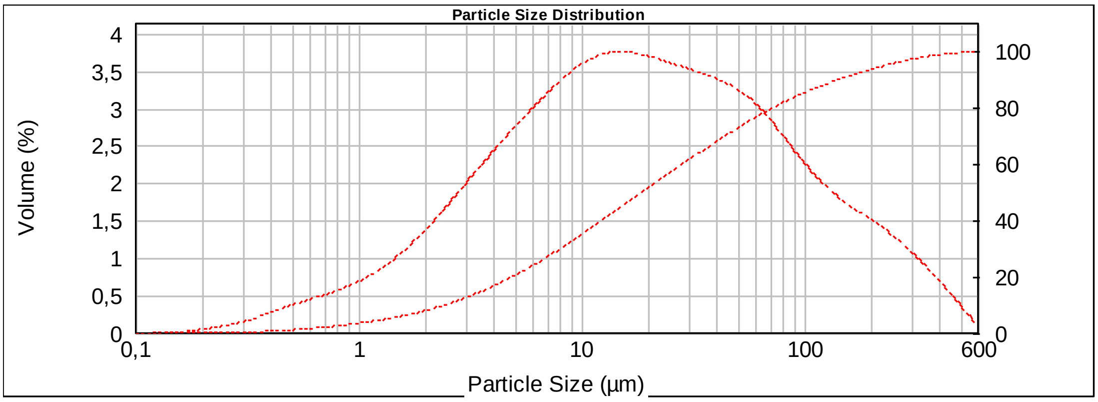
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,02
0,182	0,04
0,209	0,07
0,240	0,09
0,275	0,13
0,316	0,17
0,363	0,23
0,417	0,29
0,479	0,34
0,550	0,40
0,631	0,45
0,724	0,50
0,832	0,56
0,955	0,63
1,096	

Size (µm)	Volume In %
1,096	0,72
1,259	0,83
1,445	0,96
1,660	1,11
1,905	1,27
2,188	1,45
2,512	1,64
2,884	1,84
3,311	2,03
3,802	2,21
4,365	2,40
5,012	2,57
5,754	2,74
6,607	2,90
7,586	3,05
8,710	3,18
10,000	3,28
11,482	

Size (µm)	Volume In %
11,482	3,35
13,183	3,39
15,136	3,39
17,378	3,36
19,953	3,32
22,909	3,27
26,303	3,21
30,200	3,16
34,674	3,10
39,811	3,04
45,709	2,96
52,481	2,84
60,256	2,68
69,183	2,49
79,433	2,28
91,201	2,08
104,713	1,89
120,226	

Size (µm)	Volume In %
120,226	1,74
138,038	1,61
158,489	1,50
181,970	1,39
208,930	1,28
239,883	1,15
275,423	1,00
316,228	0,84
363,078	0,67
416,869	0,49
478,630	0,29
549,541	0,10
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.36 Particle size analysis result for “60L20S20 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

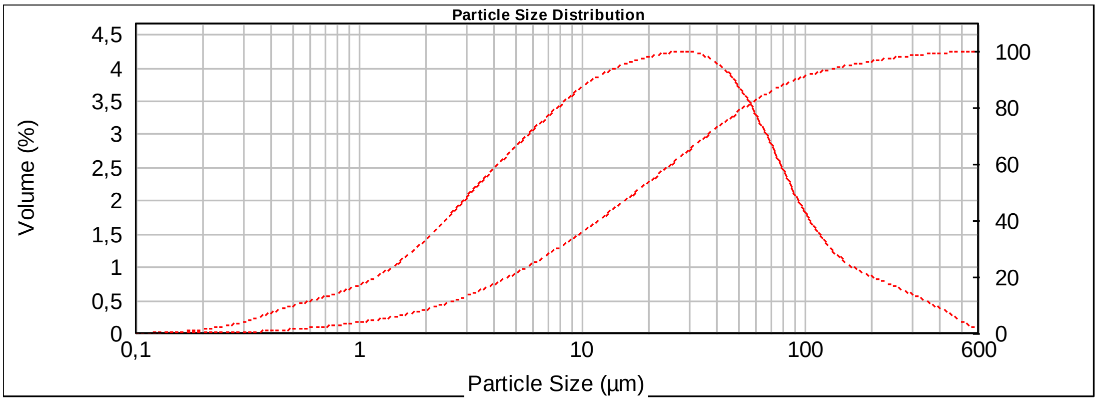
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,07
0,240	0,10
0,275	0,14
0,316	0,19
0,363	0,25
0,417	0,31
0,479	0,37
0,550	0,42
0,631	0,47
0,724	0,53
0,832	0,58
0,955	0,66
1,096	

Size (µm)	Volume In %
1,096	0,74
1,259	0,85
1,445	0,98
1,660	1,13
1,905	1,29
2,188	1,47
2,512	1,67
2,884	1,86
3,311	2,06
3,802	2,25
4,365	2,43
5,012	2,61
5,754	2,78
6,607	2,95
7,586	3,11
8,710	3,26
10,000	3,39
11,482	

Size (µm)	Volume In %
11,482	3,50
13,183	3,59
15,136	3,66
17,378	3,72
19,953	3,77
22,909	3,80
26,303	3,82
30,200	3,81
34,674	3,74
39,811	3,61
45,709	3,41
52,481	3,13
60,256	2,79
69,183	2,42
79,433	2,04
91,201	1,69
104,713	1,40
120,226	

Size (µm)	Volume In %
120,226	1,17
138,038	1,00
158,489	0,88
181,970	0,79
208,930	0,71
239,883	0,63
275,423	0,55
316,228	0,46
363,078	0,37
416,869	0,28
478,630	0,16
549,541	0,06
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



A.37 Particle size analysis result for “60S40 Separate Grinding”

Size (µm)	Volume In %
0,010	0,00
0,011	0,00
0,013	0,00
0,015	0,00
0,017	0,00
0,020	0,00
0,023	0,00
0,026	0,00
0,030	0,00
0,035	0,00
0,040	0,00
0,046	0,00
0,052	0,00
0,060	0,00
0,069	0,00
0,079	0,00
0,091	0,00
0,105	

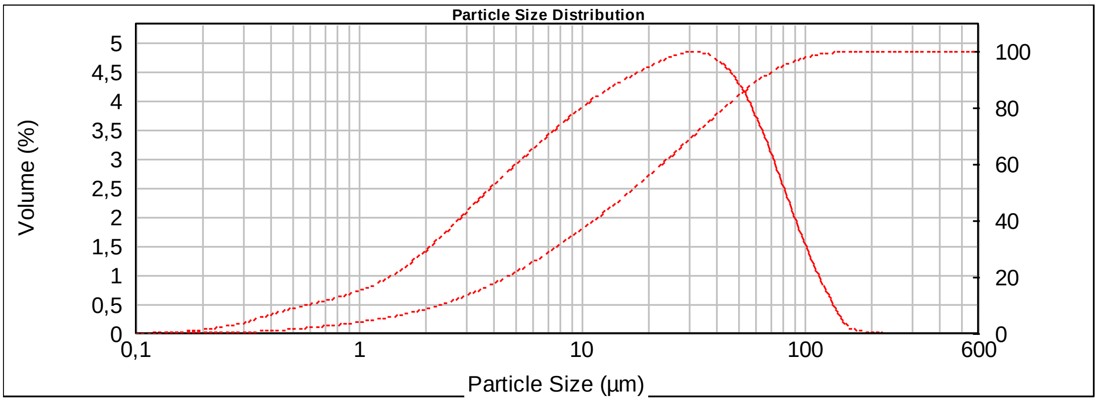
Size (µm)	Volume In %
0,105	0,00
0,120	0,00
0,138	0,01
0,158	0,03
0,182	0,05
0,209	0,08
0,240	0,11
0,275	0,15
0,316	0,20
0,363	0,27
0,417	0,33
0,479	0,39
0,550	0,44
0,631	0,49
0,724	0,54
0,832	0,59
0,955	0,66
1,096	

Size (µm)	Volume In %
1,096	0,74
1,259	0,85
1,445	0,98
1,660	1,13
1,905	1,30
2,188	1,50
2,512	1,70
2,884	1,90
3,311	2,11
3,802	2,31
4,365	2,51
5,012	2,69
5,754	2,88
6,607	3,06
7,586	3,24
8,710	3,41
10,000	3,57
11,482	

Size (µm)	Volume In %
11,482	3,72
13,183	3,84
15,136	3,96
17,378	4,07
19,953	4,17
22,909	4,26
26,303	4,34
30,200	4,36
34,674	4,32
39,811	4,19
45,709	3,95
52,481	3,59
60,256	3,13
69,183	2,59
79,433	2,02
91,201	1,48
104,713	0,98
120,226	

Size (µm)	Volume In %
120,226	0,56
138,038	0,19
158,489	0,05
181,970	0,02
208,930	0,00
239,883	0,00
275,423	0,00
316,228	0,00
363,078	0,00
416,869	0,00
478,630	0,00
549,541	0,00
630,957	0,00
724,436	0,00
831,764	0,00
954,993	0,00
1096,478	0,00
1258,925	

Size (µm)	Volume In %
1258,925	0,00
1445,440	0,00
1659,587	0,00
1905,461	0,00
2187,762	0,00
2511,886	0,00
2884,032	0,00
3311,311	0,00
3801,894	0,00
4365,158	0,00
5011,872	0,00
5754,399	0,00
6606,934	0,00
7585,776	0,00
8709,636	0,00
10000,000	



APPENDIX B

CHEMICAL ANALYSIS OF EACH CEMENT SAMPLE

		CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	Loss on Ignition	TOTAL
	100 C	62.30	20.39	5.26	3.69	1.98	3.50	0.77	0.06	1.18	99.01
INTERGROUND	**80T20**	50.92	28.94	7.42	3.41	1.61	2.62	1.22	0.67	1.28	98.09
	80T10L10	55.35	22.82	5.88	3.21	1.68	2.59	0.92	0.32	5.73	98.50
	80T10S10	53.73	26.82	7.52	3.26	2.31	2.80	1.02	0.35	1.06	98.87
	80L20	59.70	17.09	4.39	3.01	1.73	2.73	0.68	0.09	8.80	98.05
	80L10S10	58.42	20.62	5.88	3.08	2.35	2.80	0.76	0.05	4.61	98.47
	80S20	56.21	23.89	7.39	3.15	2.92	2.63	0.79	0.01	1.08	98.06
	70T30	45.21	33.32	8.54	3.30	1.42	2.27	1.43	0.91	1.38	97.77
	70T15L15	51.98	24.54	6.34	3.08	1.54	2.40	1.03	0.52	7.32	98.76
	70T15S15	49.31	29.41	8.48	3.03	2.37	2.52	1.14	0.53	1.22	98.01
	70L30	59.15	15.67	4.06	2.81	1.72	2.39	0.63	0.10	12.78	99.11
	70L15S15	56.05	21.13	6.39	2.78	2.59	2.49	0.75	0.04	6.48	98.61
	70S30	53.98	25.58	8.44	2.87	3.37	2.38	0.84	0.12	0.59	98.16
	60T40	38.83	38.71	9.97	3.21	1.25	2.00	1.69	1.08	1.60	98.33
	60T20L20	48.49	26.03	6.70	2.84	1.43	2.01	1.12	0.68	9.15	98.45
	60T20S20	45.10	32.42	9.61	2.84	2.52	1.81	1.25	0.62	1.28	97.46
	60L40	57.64	13.88	3.59	2.43	1.55	2.03	0.58	0.14	17.20	98.77
	60L20S20	53.74	20.93	6.55	2.45	2.72	2.09	0.71	0.03	8.22	97.40
	60S40	51.05	27.73	9.67	2.55	3.89	1.43	0.84	0.04	0.46	97.66
SEPARATE GRINDING	**80T20**	50.40	29.23	7.54	3.45	1.59	2.63	1.24	0.70	1.46	98.24
	80T10L10	55.54	23.33	6.03	3.28	1.71	2.72	0.96	0.33	5.14	99.05
	80T10S10	53.70	26.43	7.43	3.31	2.27	2.77	0.99	0.37	1.22	98.49
	80L20	59.52	17.45	4.54	3.09	1.83	2.74	0.69	0.09	8.97	98.74
	80L10S10	58.01	20.60	5.91	3.10	2.35	2.83	0.74	0.04	4.86	98.36
	80S20	56.54	24.00	7.39	3.12	2.91	2.92	0.82	0.01	0.86	98.58
	70T30	45.72	32.79	8.46	3.34	1.46	2.36	1.41	0.88	1.65	98.06
	70T15L15	51.85	24.67	6.39	3.07	1.58	2.43	1.04	0.50	7.22	98.75
	70T15S15	48.38	29.16	8.39	3.06	2.28	2.51	1.12	0.52	1.15	96.58
	70L30	58.47	16.07	4.18	2.79	1.75	2.44	0.67	0.11	12.82	99.07
	70L15S15	56.21	20.79	6.26	2.81	2.56	2.60	0.74	0.04	6.70	98.63
	70S30	53.54	25.79	8.45	2.84	3.37	2.19	0.83	0.01	0.67	97.69
	60T40	39.41	37.20	9.67	3.20	1.24	2.47	1.59	1.07	1.72	97.57
	60T20L20	48.12	26.18	6.72	2.83	1.43	2.15	1.15	0.66	9.14	98.38
	60T20S20	44.61	32.78	9.70	2.85	2.47	1.79	1.25	0.66	1.22	97.32
	60L40	57.42	14.71	3.88	2.53	1.70	2.11	0.62	0.12	16.60	99.45
	60L20S20	53.80	20.95	6.64	2.51	2.75	2.18	0.73	0.02	8.74	98.28
	60S40	51.02	27.32	9.49	2.57	3.83	1.27	0.81	0.02	0.43	96.77