Effect of Particle Gradation on the Strength Properties of Cemented Paste Backfill (CPB)

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ABSTRACT
A comprehensive laboratory study was performed on CPB samples collected from backfilling operations to investigate the influence of particle gradation variation on developing strength at different curing times. Two different locally sourced aggregates were used to prepare the backfill mixtures. The measurement of strength was evaluated by the uniaxial compressive strength (UCS) test on the collected specimens. The particle size distribution of each source material was determined by dry sieve analysis which showed that one material is classified as well-graded and the other as poorly graded. The observed strength after 28 days of curing is around 1 to 2 MPa for samples using the well-graded aggregates. Conversely, the UCS results are less than 1 MPa from the poorly graded aggregates where the particle size distribution analysis have lower quality values. Moreover, a comparison of tailings and aggregates are shown from the data analysis of strength and particle size distribution result.

RÉSUMÉ
Une étude approfondie en laboratoire a été réalisée sur des échantillons de CPB prélevés lors d'opérations de remblayage afin d'étudier l'influence de la variation de la gradation des particules sur le développement de la résistance à différents temps de durcissement. Deux granulats différents d'origine locale ont été utilisés pour préparer les mélanges de remblai. La mesure de la résistance a été évaluée par le test de résistance à la compression uniaxiale (UCS) sur les spécimens collectés. La distribution granulométrique de chaque matériau source a été déterminée par une analyse au tamis sec qui a montré qu'un matériau est classé comme bien calibré et l'autre comme mal calibré. La résistance observée après 28 jours de cure est de l'ordre de 1 à 2 MPa pour les échantillons utilisant les granulats bien calibrés. À l'inverse, les résultats UCS sont inférieurs à 1 MPa à partir des agrégats mal calibrés où l'analyse de la distribution granulométrique a des valeurs de qualité inférieures. De plus, une comparaison des résidus et des agrégats est présentée à partir de l'analyse des données du résultat de la distribution de la résistance et de la taille des particules.

1 INTRODUCTION

In underground mining, backfilling method is used in both cut and fill mining and open stoping mining to fill completed production openings to stabilize hanging wall formations and to facilitate mining ore adjacent to backfilled openings. Backfilling provides improvement in safety support to the engineering structures by controlling subsidence and movement of structures. It also provides sufficient workspace for mining equipment and workers, leading to an increase in ore body production.

The backfilling process should provide a feasible and economical solution for preparing the material into a competent structural product, which would be depended on the availability of abundant sources of quality materials near the mining areas. Hence, to match the engineering, economic and sustainable criteria of the backfilling operation, it is essential to make a careful selection of locally available backfilling materials from tailings, waste rock, aggregates, and metallurgical by-products (Petrolito et al. 1998; Bloss and Greenwood 1998)

In the mining industry, tailings management is one of the biggest challenges. It is increasingly common to utilize tailings as the principal constituent in Cemented Paste Backfill (CPB) for backfilling operations to reduce surface tailings storage requirements. This takes advantage of already available source material and improves the overall long-term sustainability of the mining operation.

Developing good quality backfill materials depends on the range of strength build-up as a function of particle size gradation, binder and moisture contents, curing environment and time. Among the conventional backfilling methods, paste backfill gives better support and early stabilization which often leads to high strength and stiffness (Bissonnette, 1995). Aref et al. (1989) have reported that paste fill has fast consolidation and uses less binder, usually between 2 and 7 percent. Ouellet et al. (1998) suggested that sufficient cohesion from the cement bond should be there to prevent the mining induced loading and improve the liquefaction resistance of the fill mass to ensure stability. Hedley (1995) reported that compressive strength and deformation modulus of paste fills are primarily influenced by the cement or binder content and to a less extent by porosity. Binder/water ratio and moisture content influence the development of strength properties more than particle size gradation for backfilling mixture (Chen et el, 1995). Thus, the reduced binder content and early development of strength of the CPB method lead to higher productivity and lower operating costs.

Particle size ranges and the gradation characteristic of the CPB tailing material plays a crucial role in the mechanical properties of backfill materials (Espley et al., 1970). In terms of mine backfill, the primary purpose for optimizing particle size distribution is to achieve a well-graded aggregate distribution to obtain optimum porosity which leads to reduction in binder consumption and mine operating cost (Thomas et al., 1979). Ross-Watt (1989) reported that when the fine materials increases, the strength of the paste backfill increases. Contrary, Clark (1988) experimentally showed that the presence of fine particles decreased the compressive strengths of total tailings paste backfill.

The experimental findings of Annor (1999) reported that timely improvements in compressive strength happened when the mixtures were well-graded, having wider range of particle size gradation. Then, Boldt et al. (1993) suggested that binder content and moisture control, fine portion in tailings considered to have more influence on strength development than aggregate gradation alone. He further stated that optimum water/cement ratio and grain size gradation influenced the strength development in tailings paste. At higher water/cement ratios (7 to 11), particle size gradation seems to have minor effect on compressive strength development (Boldt et al., 1993).

Generally, the backfill design is based on the capability of sustaining both the gravitational loading of the roof material and preventing subsidence. The unconfined compressive strength (UCS) test is one of the most important parameters to be considered for strength measurement when dealing with cemented backfill system. In this study, UCS test was conducted on three different days of curing with the collected backfilling sample from field operation. Then, particle size distribution analysis was conducted on the collected aggregates samples and tailings which were used as major constituents in preparing the backfilling mixtures. An approach is taken here to identify the differences in strength of different backfilling samples by comparative data analysis from the particle size distribution results.

2 MATERIALS AND EQUIPMENT

The backfilling mixture samples were collected from the field operation into cylindrical molds. After being hardened enough and curing in the cold temperature, those molds filled with backfilling mixture and some aggregates samples were transferred into the lab for testing. In the lab, the cylindrical molds were transferred to the moisture condition for curing and test was conducted on different curing days. Compositional analysis using the X-ray diffraction (XRD) method was conducted in the lab for analyzing the components in the aggregates and tailings.

Backfilling ingredients were mixed in the concrete mixing truck. Here, the mixing operation of each truck is mentioned as a batch. Around five to seven cubic meters of backfilling mixer were prepared in each batch. From the each batch mixture, samples were collected into the cylindrical molds for lab testing. The backfilling mixture were poured into the excavated zone. Batch one to batch six were prepared with the SL aggregates. Batch seven to batch thirteen were prepared with the BR aggregates. From batch one to batch thirteen, the mixture proportion by weight percentage are approximately 85% aggregates, 8% water, 5% cement, and the water to cement ratio (w/c) is around 1.47 and anti-washout additive used 1 litre/m^3. In batch one to ten, the mixing quantity of calcium chloride is about 3% by weight of the cement. But in the batch eleven to batch thirteen, the calcium chloride used around 10% by weight of the cement content. The moisture content was around 8% in all samples.

2.1 Backfill Materials

The aggregate is an extracted material from nearby sources like rivers, excavation areas, etc., which is composed of rock and mineral particles. Aggregates from natural sources are suitable backfill materials based on the availability, grain size and reserves. There are two types of aggregates and tailings have been used for preparing the backfilling mixtures in the field. The aggregates are collected from the local sources nearby the excavated area. The first one is named SL aggregates, has included in the left of figure 1 and the second one is named BR aggregates shown in the right of figure 1. The tailings are collected from the nearby mining operation area. The objective is to utilize the tailings for the backfilling operation and compare the results with the aggregates or a combination of aggregates and tailing to achieve adequate strength with minimum cost.

Figure 1: Two different aggregates.

X-ray diffraction (XRD) analysis for the aggregates has been conducted to determine the chemical composition. As shown in the figure 2 and 3, it's found that the major components for SL aggregates are Clinochlore, Quartz, Albite containing 36.4%, 24.9%, 19.2% respectively. Then, the major components for BR aggregates are Albite, Quartz, Muscovite containing 47.5%, 42.7%, 3.8% respectively. The XRD results of the tailings collected from the concerned gold mine is shown in the figure 4. Quan et el (2021) reported that the major component of the tailings is Quartz. The amount of silica and calcium contents are 31% and 5.5% respectively. Some other minor components are Calcite, Albite, Muscovite, Clinchlore.

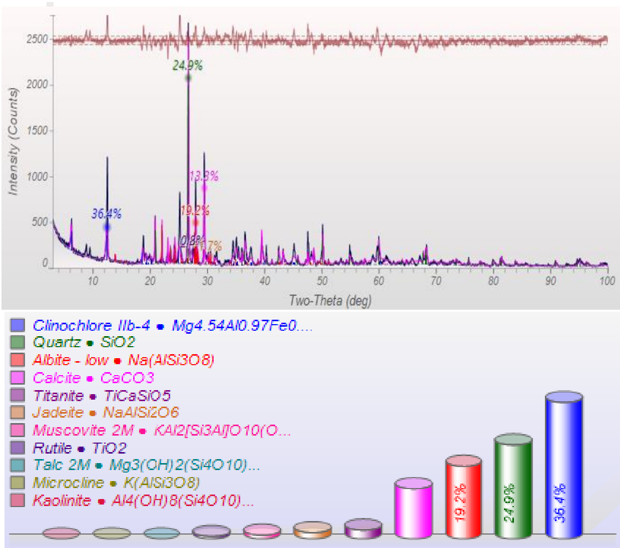

Figure 2: XRD result for the SL aggregates

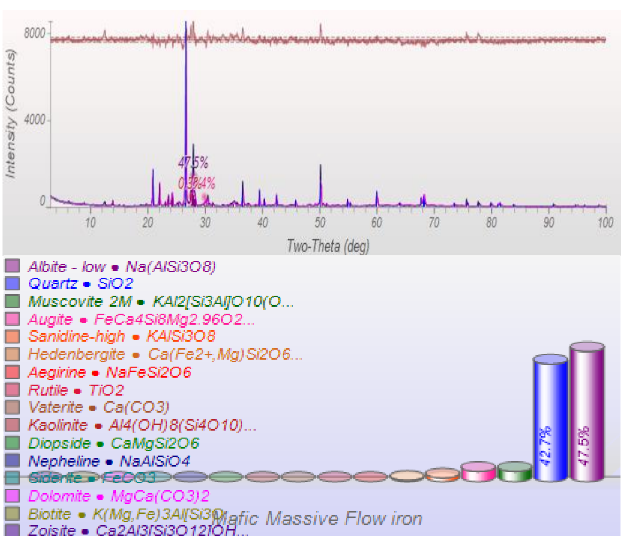

Figure 3: XRD result for the BR aggregates

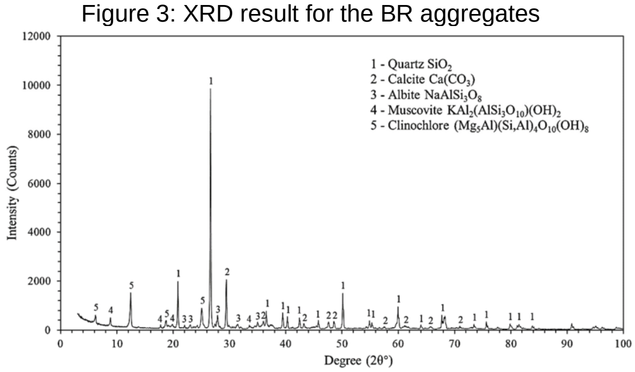

Figure 4: XRD result of tailing sample (Quan et al 2021)

2.2 Binders

For efficient backfill preparation, the evaluation of binder composition and the curing environment is important factor. Most commonly used cementitious materials such as Ordinary Portland Cement (OPC) have been utilized here. Type of binder and composition, moisture content, and water/binder ratio tend to regulate the development of strength properties in backfill material preparation. Among the backfilling mixture properties, the cost of binders/cement constitutes a significant portion compared to the other materials. The objective is to minimize the cost of cement/binders by developing the aggregates or tailings mixture to an extent where adequate strength would be gained within the required curing time.

2.3 Anti-washout Additive

The excavated zone where the backfilling mixture has been poured is filled with water. When the cement mixture is poured into the water without adding any specific additives, it affects the binding ability of the cement with aggregates. In that case, the underwater concrete method would minimize this effect. The underwater concrete method is widely used in offshore construction, bridges, and foundations in soil with the water level. The underwater concrete is highly flowable concrete that can spread into place under its own weight and get good compaction without vibration. The anti-wash additives mixture provides the resistance to washout, segregation, bleeding in case the concrete is washed out during the placement. The anti-washout additive is substantially influential in enhancing the cohesiveness and rheological properties of backfilling mixture that is poured in water.

2.4 Accelerator

Usually, the accelerator in the concrete admixture shortens the curing time and increases the rate of early strength development. The cold weather influences the concrete's slow curing and delays the setting process. Due to cold temperature, water in the concrete is prone to freeze and expand, cracking and weakening the strength of the concrete. Adding an accelerator makes the hydration process of the concrete faster and the set time can be reduced significantly. In the concrete mixture industry, calcium chloride as an accelerator has been very popular. During backfilling operation in winter, the temperature was cold there and there was no concern of rebar corrosion which makes the calcium chloride convenient considering the cheap cost and availability. During the mixture of backfilling, calcium chloride in different batches with varying percentages has been used as the accelerator.

2.5 Particle Size Distribution Analysis

Particle size distribution analysis is an analytical procedure to determine the range of the coarse and finer aggregates. The analysis is followed by arranging several layers of sieves with different grades of sieve opening sizes. Particle size distribution can influence the properties like the strength of concrete, solubility of mixture. Among all the available sieve analysis procedures, the dry sieve analysis has been conducted in this study. Particle size distribution has been conducted using the two widely used ASTM standards. The first one is ASTM D6913 – particle size distribution (gradation) of soils using sieve analysis, then ASTM C136 – sieve analysis of fine and coarse aggregates.

Sample splitter has been used to obtain a representative portion of the materials. This procedure is followed by according to the ASTM standard C702 – reducing samples of aggregates to testing size. In the figure 5, the sample splitter has an even number of equal width chutes. The splitter is equipped with two receptacles to hold the two halves of the samples following splitting. Samples are fed to the hopper at the top portion and fed to the chutes at a controlled rate. The sample needs to flow smoothly without restriction or loss of materials.

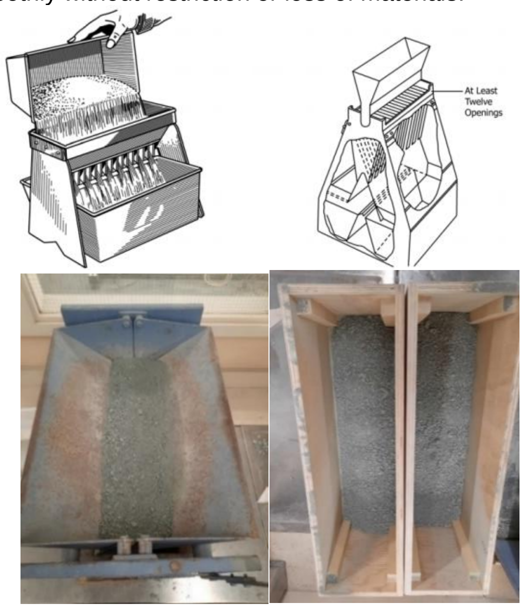

Figure 5: Sample Splitters (Riffles) – ASTM C702

3 EXPERIMENTAL ANALYSIS

3.1 Slump Test

The slump test measures the consistency of the freshly mixed concrete batches before it is set to maintain the standard of quality and strength. It measures the workability of the concrete and determines how easily the concrete will flow when it is poured into the site. It provides a good indication of the water-cement mixture ratio. Annor (1999) reported that the workable limits for paste fill mix design and stabilization were found to be between 176mm and 228mm slump. The standard was followed for measuring the slump of the mixer using the method stated in the ASTM standard C143 – slump of hydraulic cement concrete. The slump test was conducted immediately after the mixer occurred in the concrete mixing truck. The measured average distance of the slump is around 9.43 inches (239mm).

Figure 6: Slum test for the backfilling mixtures using SL aggregates (Batch 1).

3.2 Uniaxial Compressive Strength (UCS) Test

From the collected samples, samples were categorized for testing on different days during the curing process to observe strength development over time. The samples were collected in the 2" x 6" molds. The UCS test was conducted using the geomechanics loading frame assembled with load cell, linear variable differential transformer (LVDT) and the data acquisition system (DAQSys). The UCS test was conducted on the 10, 17, and 28 days of curing using the geomechanics loading frame. In the figure 7, the left side picture shows the collected backfilling sample made from SL aggregates and the right picture shows the sample made with BR aggregates. From each batch, three samples were tested for each testing phase and the average result is represented in the following section of result analysis. As the batch one to batch six made with SL aggregates, the average UCS results are shown in a specific figure 9. Then, batch seven to batch ten made with BR aggregates and the average UCS results are shown in the figure 10. For having different accelerator percentage in batch eleven to batch thirteen, the average UCS results are shown in the figure 11.

Figure 7: Backfilling sample in UCS testing

According to the ASTM standard C39 - compressive strength of cylindrical concrete specimens, the length, and diameter ratio of the samples were measured as 2.2. The samples were cut by a saw cutter to maintain the length to diameter ratio specified by standard and prepared for the UCS test. The average diameter of most samples was around 50.5 mm and the average length of most samples was around 115 mm.

The frictional forces between the ends of a compression specimen and the loading plates influence the specimen's measured compressive strength and failure type. During concrete compression testing, it is essential to reduce frictional forces. The presence of friction affects the stress-strain curve development significantly. According to the annual book of ASTM standards 2003, volume 4.02 “manual of aggregate and concrete testing”, the fracture type may help to determine the reason for the compressive strength of a tested cylinder being less than anticipated. Following ASTM C39, the most observed fracture pattern is Type 2 and Type 3 in the UCS test. Only a few samples produced Type 1 fracture. Type 4, 5 and 6 fractures have not been observed in any sample.

3.3 Sieve Analysis

The tailings and aggregates are collected from the local mining operation area. For the SL aggregate, the maximum size is passing 100% through the 12.5mm sieve. Also, in the 11.2mm and 9.5mm sieve size, the weight percentage retained on the sieve is less than 1%. From the BL aggregates the maximum aggregate size is passing 100% through the 11.2mm sieve. In the, 9.5mm sieve size, the weight percentage retained on the sieve is less than 1%. Hence, the single set sieve analysis was conducted for this aggregate. Those samples were dried in the oven for around 12 to 14 hours. Then they were put in the sample splitter by following the proper sampling procedure according to the ASTM standard C702. Among the two receptacles of the splitter, samples from the one receptacle was taken for the sieve analysis. In the following figure 8, the particle size distribution curve of aggregates and tailing has been shown along.

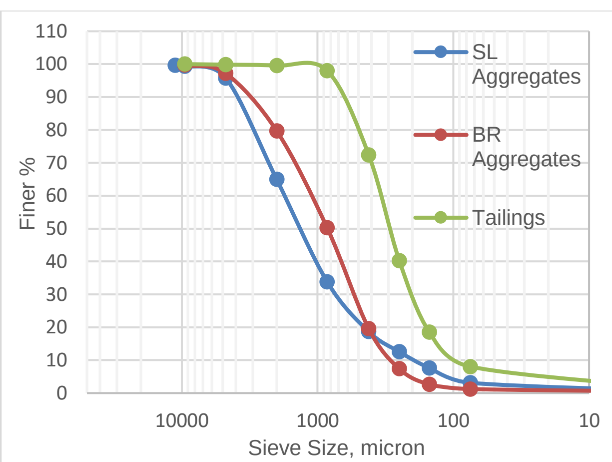

Figure 8: Particle size distribution curve of aggregates and tailings.

4 RESULT AND DISCUSSION

4.1 UCS Result

The observed range of UCS results on all the samples of batch one to batch six has shown in figure 9. After 10 days of curing, from all the tested samples the minimum UCS result is 0.96 MPa and the maximum UCS result is 2 MPa. The average result is 1.32 MPa. For the samples of 17 days of curing, the minimum UCS result is 1.03 MPa and the maximum UCS result is 2.05 MPa. The average result is 1.4 MPa. Moreover, for the samples of 28 days of curing, the minimum UCS result is 1 MPa and the maximum UCS result is 2.21 MPa. The average result is 1.5 MPa. The green line indicates the average results which is a progressive increase of strength over the curing period.

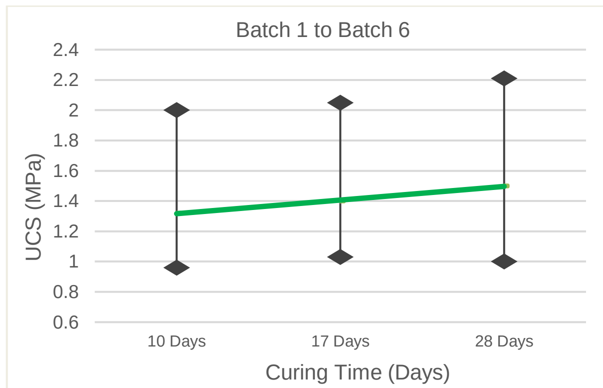

Figure 9: UCS results of samples from batch 1 to 6 on different days of curing.

For batch seven to batch ten, the observed range of UCS results on all the samples has shown in figure 10. After the 10 days of curing, the minimum UCS result is 0.53 MPa and the maximum UCS result is 0.87 MPa, then the average result is 0.64 MPa. For the samples of 17 days of curing, the minimum UCS result is 0.65 MPa and the maximum UCS result is 0.93 MPa, as well as the average result, is 0.75 MPa. Moreover, for the samples of 28 days of curing, the minimum UCS result is 0.75 MPa and the maximum UCS result is 1.05 MPa, as well as the average result is 0.81 MPa.

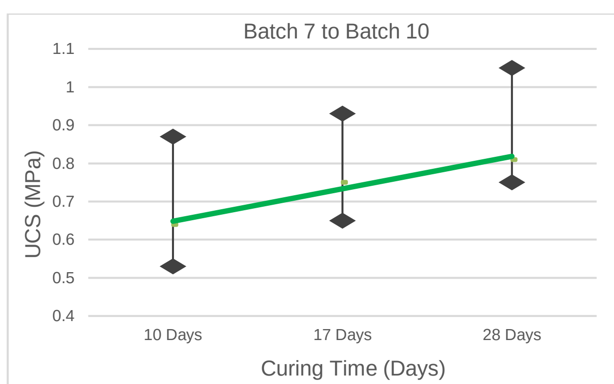

Figure 10: UCS results of samples from batch 7 to 10 on different days of curing.

From batch eleven to batch thirteen, the observed range of UCS results on all the samples is shown in figure 11. After the 10 days of curing, the minimum UCS result is 0.62 MPa and the maximum UCS result is 0.73 MPa, then the average result is 0.69 MPa. For the samples of 17 days of curing, the minimum UCS result is 0.73 MPa and maximum UCS result is 0.87 MPa, as well as the average result, is 0.80 MPa. Moreover, for the samples of 28 days of curing, the minimum UCS result is 0.80 MPa and maximum UCS result is 0.92 MPa, as well as the average result is 0.86 MPa.

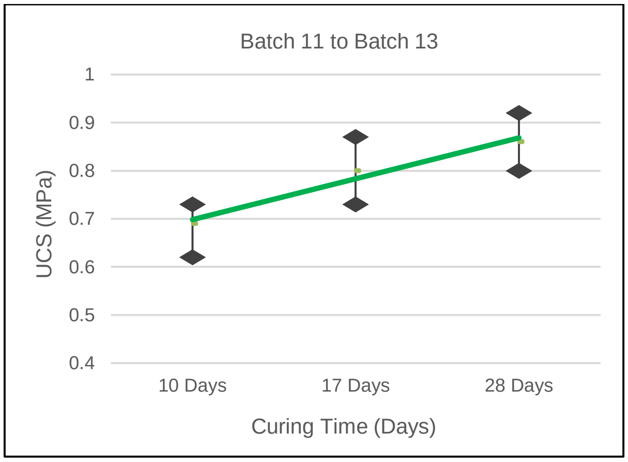

Figure 11: UCS results of samples from batch 11 to 13 on different days of curing.

Quan et al (2021) did the experimental analysis of UCS results of CPB samples made from tailings and cement. The mixture recipe of solid content, cement water ratio was almost same as the mixture recipe of CPB samples made from aggregates. Using the binder content of 6% by weight, the samples were prepared in the two-inch molds and the length to diameter ratio was 2.1. The average UCS results after 14 days is around 1.20 MPa and 28 days of curing is nearly 1.35 MPa.

4.2 Gradation of Aggregates

A renowned developed relationship available between compressive strength and sizes of aggregate materials in the concrete mixing technology. The proper selection of particle size distribution leads to optimum design of concrete mixes and minimization of cement requirements (Neville, 1987).

Well-graded aggregates have different particle sizes from coarser to finer in an adequately distributed manner. On the other hand, in the poorly graded aggregates, the particle sizes have an excess of specific particle sizes or deficiency of a certain range of particle sizes. The gap-graded particle sizes also have missing of different ranges of particles. It may have a few certain ranges of excessive particles compared to the wide range of balanced particles like the well-graded. In the following figure 12, a depiction of the typical aggregate gradation drawing has been shown.

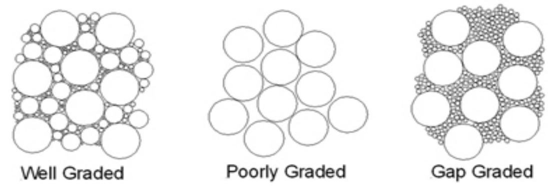

Figure 12: Conceptual drawing aggregate gradation (Courtesy of CCI)

Thomas et al. (1979) reported that adequate fine particles in a well-graded backfilling materials tend to fill the void between larger particles which leads to a reduction in the porosity and cement usage. On the other hand, the poorly graded aggregates have a high void ratio and require excess cement to fill the voids. Moreover, if there are too many fine particles, then those aggregates may consume more cement. An excess amount of fine will reduce the strength.

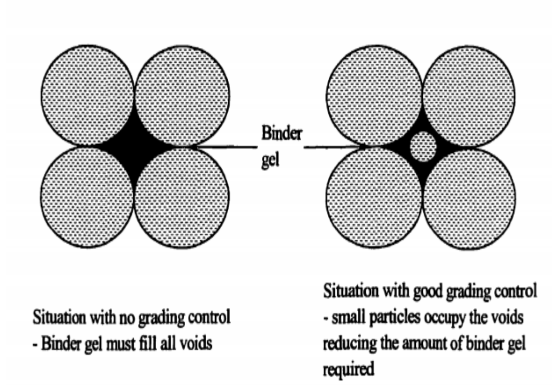

Figure 13: Model demonstrating the benefit of the good grading in particles distribution and required binder content (Thomas et al, 1979)

According to Holtz and Kovacs (1981), the analytical approach for the aggregate gradation was conducted by coefficient of curvature (C_c) and uniformity coefficient (C_u) using certain grain diameters D, which refers to equivalent percent passing on the particle size distribution curve. For example: D_{60} is the sieve size through which 60% of soil will pass through them, i.e.: 60% of the particle size is finer than this size. D_{30} is the sieve size through which 30% of soil will pass through them, i.e.: 30% of the particle size is finer than this size. D_{10} is the sieve size through which 10% of soil will pass through them, i.e.: 10% of the particle size is finer than this size.

The Uniformity Coefficient is defined by

$$C_u = \frac{D_{60}}{D_{10}} \quad [1]$$

The Coefficient of Curvature is defined by

$$C_c = \frac{(D_{30})^2}{D_{10}\ x\ D_{60}} \quad [2]$$

The aggregates are considered to be well-graded with coefficient of curvature (C_c) between 1 to 3 as long as the uniformity coefficient (C_u) is also greater than 4 for gravels and 6 for sands (Holtz and Kovacs, 1981).

Table 1: Data analysis of particle size distribution

D Values	SL Aggregates (micron)	BR Aggregates (micron)	Tailings (micron)
D_{10}	198.20	286.50	88.99
D_{30}	741.10	566.10	202.83
D_{60}	1817.18	1230.50	354.34
C_u	9.50	4.30	3.98
C_c	1.60	0.91	1.30

According to the gradation theory, the SL aggregates is well-graded since it meet the criteria $C_u > 6$ and $1 < C_c < 3$. But the BR aggregates and tailings are considered poorly graded as they don't meet either of the criteria $C_u > 4$ and $1 < C_c < 3$. For the SL aggregate from the total weight, 5%, 4.5%, and 3% were retained on 150, 75 microns, and Pan consecutively. For BR aggregate from total weight 4.75%, 1.4%, and 1% retained on 150, 75 microns, and Pan consecutively. There is a higher percentage of large size particles in the BL aggregates compared to the finer size particles. The SL aggregates have a well-balanced distribution of large and finer size particles compared to the BR aggregates. On the other hand, the D values of the tailings compared to the aggregates represent that the tailings had significant finer particles than both aggregates.

5 CONCLUSION

Appropriate particle size distribution facilitates achieving the optimized strength characteristic of the cemented paste backfill (CPB) structure. Well-graded materials minimize the porosity, increase the contact area between particles, and decrease the use of cement that fills the voids, thus reducing the cost of cementing materials for producing the required UCS strength. Also, early comprehensive strength achievement occurs for CPB mixture with a broader particle size distribution range.

Moreover, the optimum strength development of CPB depends on water / cement ratio, moisture content, binder composition, particle gradation, curing conditions. In the backfilling operation, the cement/binder cost constitutes the most. To minimize that, a combined and correlated investigation approach requires for feasible backfill mixture development. In this study, both the C_c and C_u values have been utilized to categorize the particle gradation. The findings from experimental analysis refer that the SL aggregates meet the gradation criteria well and produce required strength, around 1 to 2 MPa along their different curing periods. On the other hand, the BR aggregates don't meet the gradation criteria properly and developed strength is less than 1 MPa over different curing durations. Hence, being poorly graded and considering the safety criteria comparatively, the developed average strength for BR aggregates and tailings is lower than SL aggregates.

Further study and experimental analysis can be conducted on the composite material with mixes of tailings and aggregates maintaining a balanced mixture recipe. Modification of tailings by removing or adding different range particles can be done to make it well-distributed material. The use of non-standardized aggregates and tailings together can produce a composite mixer to achieve an optimized well graded particle size distribution. Following that, controlling moisture content and optimizing water/cement ratio can be another approach to develop the required strength.

6 REFERENCES

Annor, A.B. 1999. A Study of the Characteristics and Behavior of Composite Backfill Material, in Department of Mining and Metallugical Engineering, McGill University: Montreal.

Aref, K. Hassani, F. P. and Churcher, D. A. 1989. A study on liquefaction potential of paste backfill, in Proceedings: *Fourth International Symposium on Mining with Backfill Innovations in Mining Backfill Technology, Montreal, Canada*, 405-414.

ASTM C39. 2021 - *Compressive strength of cylindrical concrete specimens*. ASTM International, PA, USA.

ASTM C136. 2014. *Sieve analysis of fine and coarse aggregates*. ASTM International, PA, USA.

ASTM C143. 2020. *Slump of hydraulic cement concrete*. ASTM International, PA, USA.

ASTM C702. 2011. *Reducing samples of aggregates to testing size*. ASTM International, PA, USA.

ASTM D6913. 2017. *Particle size distribution (Gradation) of soils using sieve analysis*. ASTM International, PA, USA.

ASTM Annual Book of 2003, Volume 4.02. *Manual of Aggregate and Concrete Testing*. ASTM International., PA, USA

Bissonnette, B. 1995. Paste fill plant operation at the Louvicourt Mine, *Paste Backfill Seminar*, Hotel Confortel Val d'Or, Quebec, CANMET Division Report MRL 95 – 140.

Bloss, M. L. and Greenwood, A. G. 1998. Cemented rock fill research at Mount Isa Mines Limited 1992-1997. In: Minefil 198, *proceedings of the sixth international symposium on mining with backfill*, 14-16 April, in Brisbane. M. Bloss, ed. Brisbane: Australasian IMM, pp. 207-215.

Boldt, C. M. K. Atkins, L. A. and Jones, F. M. 1993. The backfilling research being conducted by the U.S. Bureau of Mines, *Minefill 93*, Johannesburg, pp. 389 - 395.

Chen, L. J. and Annor, A. 1995. A study on the properties of gold mine tailings fills, Presented at *97th Annual General Meeting of CIM Rock Mechanics and Strata Control Session*, Halifax, N.S., Canada,

Clark, I. H. 1988. The properties of hydraulically placed backfills, in *Proceedings: Backfill in South Africa Mines, Johannesburg,* SAIMM, 15-33.

Craig, R. F. 2004. *Soil mechanics*, Seventh edition, Van Nostrand Reinhold.

Espley, G. H. Beattie, H. I. and Pasieka A. R. 1970. *Cemented hydraulic backfill within the Falconbridge group of companies, CIM Bulletin*, 1002-1010.

Hedley, D G F, 1995. Final report on the stiff backfill project for M.R.D., *Mining Research Directorate, Canadian Rock burst Research Program*, Sudbury, Ontario.

Holtz D. R., Kovacs W. D. 1981. *An Introduction to Geotechnical Engineering*, ISBN 0-13-484394-0, Prentice Hall, New Jersey, USA.

Neville, A. M. 1987. Properties of concrete, *Longman Scientific and Technical-Longman*, Singapore.

Ouellet, J. Bidwell, T. J. and Servant, S. 1998. Physical and mechanical characterization of paste backfill laboratory and in-situ testing. In: *Mine fill 98, proceedings of the sixth international symposium on mining with backfill*, Brisbane Australia, 249-253.

Quan, W. Someehneshsin, J. Abugharara, A. Zhang, Y. and Butt, S. 2021. Effects of low binder proportions and internal vibration on early age behaviour of cured cemented tailings backfill for mining by drilling applications. *55th US Rock Mechanics / Geomechanics Symposium*, ARMA 21-1753, Houston, Texas, USA.

Ross-Watt, D. A. J. 1989. Backfilling on the base metal mines of the Gold Field Group, in Proceedings: *Fourth International Symposium, Innovations in Mining with Backfill*, Montreal, Canada, Publication, A.A. Balkema, pp. 351-360.

Someehneshin, J. Quan W. Abugharara, A. & Butt, S. (2020). Assessment of Freestanding Vertical Face for the Backfill Using the Run of the Mine Tailings and Portland Cement. *54th US Rock Mechanics / Geomechanics Symposium* ARMA, 20(A), 1882nd ser.

Someehneshin, J. Quan, W. Abugharara, A. & Butt, S. (2020). Backfill analysis and parametric evaluation of the cement binder on cured strength and curing time. *GeoCalgary*, Alberta.

Thomas, E. G. NanteI, J. H. and by Notley, K.R. Fill technology in underground metalliferous mines. Published by *International Academic Services, Queen's University*, 1979