Management of Tailings Stabilized by Lime and CEMENT at Canadian Electrolytic Zinc, Valleyfield, Québec

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Abstract

The zinc refinery operated by Canadian Electrolytic Zinc (CEZinc) in Valleyfield, Québec produces a tailing referred to as " jarosite". Until 1998, the jarosite slurry was deposited in ponds contained by clay dykes. Jarosite settles out to a very low consistency and its acidic pore water contains high metal concentrations. Because of these characteristics, construction and closure of the jarosite ponds was very costly.

In 1998, CEZinc implemented a new process that stabilizes the jarosite chemically and physically to form an essentially inert waste referred to as "jarofix". In addition a new concept was also developed for its storage. The main characteristics of the jarofix production process and its storage are as follows:

- The jarosite tailing is washed and thickened at the plant;
- Lime, cement and water are added to the thickened tailing (paste) to make the jarofix;
- The jarofix is hauled by trucks to the disposal area;
- A dry stacking technique is used at the jarofix disposal area, involving thin layer deposition and allowing each layer to cure and solidify to a stiff consistency.

The dry stacking concept had to take into account the jarofix depositional characteristics, the geometry of the disposal site, water and wind erosion prior to curing, the management of the runoff water, the feasibility of using the cured jarofix to build the containment dykes as well as progressive rehabilitation of the filled areas.

The jarofix is dumped from an inclined ramp that is raised progressively. Near the widest section of the disposal area, the jarofix stack will reach a height of 30 m. The initial storage facility built in 1998 included a 3 m high perimeter containment starter dyke, an 8 m high internal ramp and a separate runoff collection and clarification pond.

The properties of the jarofix within the stack are monitored every year. The cured jarofix has the consistency and strength of very stiff clay offering good resistance against erosion by wind and water. Its hydraulic conductivity is in the order of 10^{-4} to 10^{-6} cm/sec. Because cured jarofix is easy to excavate and compact and chemically stable, it makes an excellent fill material for raising the containment dykes.

Introduction

Canadian Electrolytic Zinc (CEZinc) operates a zinc refinery on the north shore of the Beauharnois Canal, in Valleyfield, Québec (see Figure 1).

The plant and its process have been modernized a few times since it's commissioning in 1963. Since 1975, CEZinc produces a tailing referred to as "jarosite" ($NH_4\ Fe_3\ (SO_4)_2\ (OH)_6$). Until 1998, the jarosite slurry was hydraulically transported at a solid content of about 22% into ponds contained by clay fill dykes. Jarosite was discharged directly from the end of the tailings pipeline. After tailings deposition, supernatant water was re-circulated to the plant. Between 1975 and 1998, jarosite was deposited successively into Tailings Ponds No. 4, 5A, 5B and 5C located west of the plant, see Figure 1. The main physical

properties of jarosite are indicated in Table 1. Jarosite has the grain size distribution of silt with traces of clay. The consistency of jarosite after settling out in the pond is very soft; it is not possible to walk on jarosite beach. The jarosite pore water is acidic with high concentration of dissolved metals.

Because of these characteristics, the construction and the closure of the jarosite ponds required costly measures and careful control to prevent potential detrimental environmental impacts. As an example, the design of Pond 5C, built between 1990 and 1993, included the lining of the entire floor with plastic membrane to prevent seepage losses to the ground water regime. Furthermore, at closure, the entire surface of the jarosite pond was capped with a multi layer soil-geosynthetic cover.

Description of the Jarofix Process

In 1998, CEZinc implemented a new process that stabilizes the jarosite chemically and physically to form an essentially inert waste referred to as "jarofix". In addition a new concept was also developed for its storage. The main characteristics of the jarofix production of about 184 000 t of solids per year and its storage are as follows:

- The jarosite is washed and thickened at the plant using vacuum filters;
- Lime, cement and water are added to the thickened jarosite (paste) to make the jarofix;
- The jarofix is hauled by trucks to the disposal area;
- A dry stacking technique is used at the disposal area. This involves thin layer deposition and allowing each layer to cure and solidify to a very stiff consistency.

Development of the Jarofix Dry Stacking Concept

Laboratory Testing and Modeling

The first step of the development of the dry stacking concept consisted of laboratory testing and stack modeling. The main objectives of these tests were to simulate the behaviour of fresh jarofix during and after its deposition at the storage site and to determine the feasibility of using the cured jarofix to build containment dykes and service roads.

The laboratory tests and modeling, which were carried out in 1996, included (a) Geotechnical identification tests (grain size distribution, density, unit weight, Proctor compaction, direct shear, hydraulic conductivity, etc.), (b) Bench scale simulations of jarofix deposition to determine the depositional angle, the thickness of the jarofix layer deposited, the erosion resistance of the fresh and cured jarofix exposed to design rain and wind intensities and (c) Conventional tests to determine the undrained shear strength of jarofix as a function of curing time.

The main results of the laboratory tests are as follows:

- Up to 90 minutes after cement addition, the jarofix paste remains sufficiently fluid to be hauled by trucks;
- Fresh jarofix has a natural depositional slope of about 10%, flows and stacks at an average uniform thickness of about 10 cm for the design mix. However depending on various parameters (cement content, water content, etc.), the jarofix depositional slope and flow layer thickness could vary widely.
- All tests, on fresh or cured jarofix demonstrated good resistance against wind erosion for the average winter wind velocities simulated; however some tests indicated that extreme peak wind velocities could cause erosion locally in the jarofix stack.
- Under a 10 year, 30–min rainfall of 30 mm, fresh jarofix erodes at a rate of 1 to 2 kg/m^2; however, after 2 to 3 hours of curing, the rate of erosion becomes negligible.
- Cured jarofix was found to be an excellent fill material for construction of dykes and roads.

Design of the Jarofix Disposal Area

The design of dry stacking facility was developed on the basis of the following criteria:

- Provide a minimum service life of 25 years, with the disposal site extended every 5 years;
- The jarofix dumping faces should be oriented to avoid predominant wind directions;
- The system should allow progressive rehabilitation of part of the completed disposal area;
- A pond had to be built to collect and clarify the runoff water and also to allow verification of the water quality, and its treatment if required, before its release into the receiving natural watercourse.

The jarofix disposal area is designed as a dry stacking site. The jarofix paste is hauled to the site using trucks adapted for the purpose (see Figure 6). The waste is dumped from an inclined ramp that is raised progressively as the jarofix level rises. The disposal area is progressively extended starting from the narrow end towards the west. When a significant area of the facility is filled to the design height, progressive closure is carried out. The closure cover consists of placing topsoil and grass seeding. Figures 2 and 3 illustrate the progressive developmental concept of the disposal area. The height of the jarofix stack will reach 30 m near the widest end of the wedge shaped storage facility.

Construction of the initial structures

The initial or start-up facility built in 1998 included a 3 m high starter dyke an 8 m high internal dumping ramp, a system of ditches and a separate pond to collect and clarify runoff. The pond is divided into compartments with filter dykes and is equipped with a pumping station and instruments needed for checking the water quality. Figure 4 illustrates the disposal area at the end of construction in 1998.

Every year the jarofix stack is surveyed to record its progress and adjust its deposition plan. The extent of the stacked jarofix in December 1999 and Summer 2000 are shown on Figure 7 and Figure 5, respectively. The jarofix deposition slope has an average inclination of 10% and the average thickness of the fresh jarofix strata is about 10 cm, as determined by bench scale deposition tests in the laboratory. Figure 8 shows a typical jarofix depositional slope at the disposal site.

In Summer 2000 the starter dyke was extended and raised using cured jarofix as fill material. The jarofix was excavated from a designated area, hauled to the starter dyke location, spread with bulldozers and compacted in 300 mm thick lifts with compactors (see Figures 9 and 10).

Extension and raising of starter dyke was also carried out in Summer 2001 and 2002 using jarofix as fill material. In Summer 2002, where the jarofix reached its final level, it was covered with topsoil and seeded.

Physical Properties of Jarofix

Sampling of Cured Jarofix

Five campaigns of investigation have been carried out since the commissioning of the jarofix process in October 1998. The cured jarofix in the stack is sampled using standard geotechnical drilling equipment, such as a CME 75 drill mounted on tracks.
Standard 51 mm diameter split spoon is the best sampler for the cured jarofix. In addition, a 73 mm diameter Shelby tube also gives good results when intact jarofix samples are required. Experience has shown that core barrels, such as HQ3, are not good sampling devices for the jarofix.

Temperature of Jarofix

The temperature of the jarofix samples, as measured at the site during sampling, is shown on Graph (a) of Figure 11. The temperature of jarofix increases from the surface of the stack to about the mid-height and then decreases to the bottom of the stack. The highest temperature measured in a jarofix sample is 28°C.

Grain Size, Moisture Content and Dry Unit Weight

As shown on Figure 13, jarofix has grain size distributions similar to that of silt with traces of sand and clay. It is seen that the clay content (particles smaller than 2 microns) of jarofix fill

samples is about 28% compared to 15% or less for the jarofix sampled from the disposal site. This difference in the fines content is attributed to particle breakage during compaction in the fill samples.

Moisture content is defined as the weight of the pore water divided by the total weight of the sample (not to be confused with the geotechnical water content which is the weight of the pore water divided by the dry weight of the soil). The in-situ moisture content of cured jarofix generally varies between 38 and 45% with an average value of about 41 to 42% (see Graph (b) of Figure 11). The values for compacted jarofix are generally smaller than the above, because of loss of moisture by evaporation during fill placement and compaction.

The average specific gravity of solids of jarofix is 3.4. The dry unit weight of cured jarofix varies between 909 and 1042 kg/m^3 with an average value of about 962 kg/m^3 (see Graph (d) of Figure 11). The dry unit weight of compacted jarofix is slightly higher varying between 970 and 1079 kg/m^3 and averaging about 1028 kg/m^3.

Consistency and Strength of Jarofix

The consistency of jarofix at the disposal site was determined by Standard Penetration Tests (N value). Graph (e) of Figure 12 shows that the N values vary between 2 and 29, thus indicating a relatively large variation in the consistency of the jarofix. Generally the N value increase with depth in the stack.

The in-situ undrained shear strength of jarofix was measured in 2002 using a Nilcon vane apparatus. The results of two tests were 180 and 189 kPa, thus indicating that cured jarofix has the strength of a very stiff clay.

The uniaxial compressive strengths, as determined on 16 intact samples, vary between 105 and 634 kPa, with an average value of 340 kPa (see Graph (f) of Figure 12), which compares well with the Nilcon test values.

Two CIU triaxial tests with pore water pressure measurements resulted in a peak effective friction angle of 70° and no cohesion. The residual strength (at about 5% strain) is characterized by an effective friction angle of 52° and no cohesion (see Figure 14).

Hydraulic Conductivity of Jarofix

Hydraulic conductivity tests were carried out within piezometers installed for this purpose in the jarofix stack. Laboratory tests in triaxial cells were also carried out on intact samples recovered from the boreholes. The measured in-situ hydraulic conductivities are presented on Graph (g) of Figure 12. Generally, the in-situ hydraulic conductivity varies between 5 x 10^{-6} and 5 x 10^{-3} cm/s with most of the results falling in the range of 1 x 10^{-5} to 1 x 10^{-4} cm/s. The values obtained in laboratory generally fall between 7 x 10^{-7} and 4 x 10^{-6} cm/s. It is to be noted that the tests carried out in laboratory measure the vertical component of the hydraulic conductivity, whereas the in-situ tests are affected mainly by horizontal flows.

Conclusion

The use of thickened or “paste” tailings with or without the addition of a binder like cement, is getting a wider acceptance in the mining and the metallurgical industry. The objectives of thickening vary for each mine site and depend on the type of tailings, the metallurgical process, the site location, the climatic condition, etc.

In 1998, CEZinc commissioned a new process with the main objective being the chemical and physical stabilization of its jarosite tailing. In comparison with the jarosite tailings, the main advantages of the new stabilized waste product referred to as “jarofix” are as follows:

- Jarofix is chemically inert, thus eliminating all short and long-term environmental risks during and after its disposal.
- Cured jarofix is a physically stable mass. As the result the disposal area could be reused for other purposes in the future.

Acknowledgements

The authors would like to acknowledge the permission of Noranda inc. CEZinc to prepare this

paper. In addition, the authors would like to recognise the contributions of CEZinc personnel specially Sylvain Seyer and Daniel Daoust and SNC◆LAVALIN Environment personnel, in particular Raynald Lemieux and Martin Champoux to the overall project.

Parameter	Typical Value
Grain size distribution Sand, % (0,08 to 5 mm) Silt, % (0,002 to 0,08 mm) Clay, % (lower than 0,002 mm)	 0,5 88,6 10,9
Liquid limit, %	24,8
Plastic limit, %	21,7
Plasticity index, %	3,1
Water content, %	50 to 70
Total unit weight, N/m^3	15 to 19
Specific gravity of solids	3,53
Hydraulic conductivity (in laboratory), cm/s	1×10^{-6} to 1×10^{-5}
Undrained shear strength (Nilcon), kPa	5 to 15
Static penetrometer resistance, kg/cm^2	0,5 to 4,0

TABLE 1. Physical properties of jarosite

FIGURE 1. Site location, jarosite ponds 5A, 5B, 5C are located in the top left corner of photo.

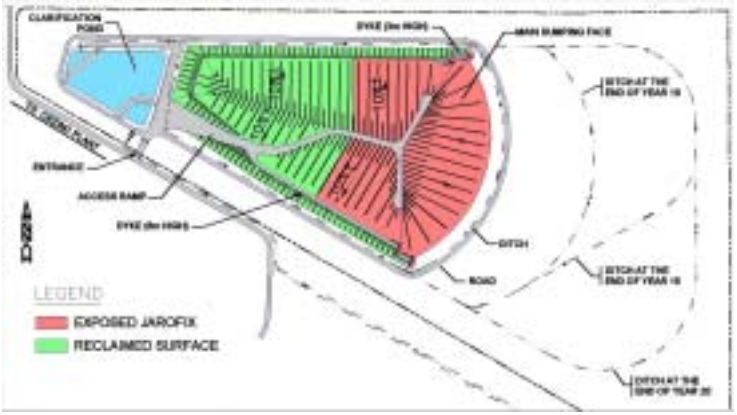

FIGURE 2. Progressive developmental concept – End of year 5

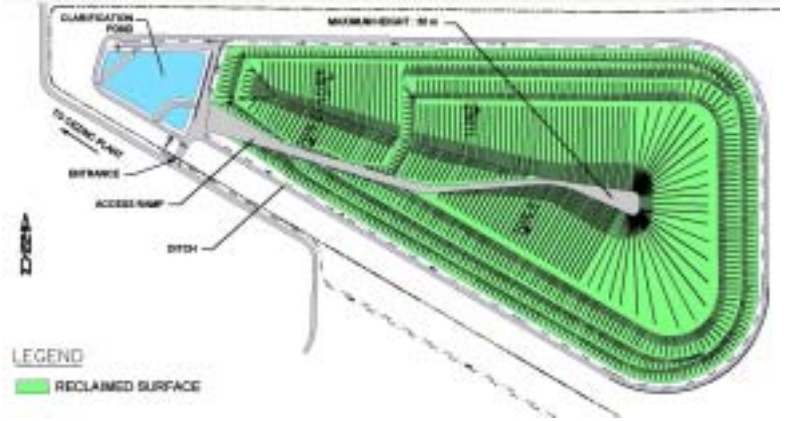

FIGURE 3. Jarofix stacking at the end of year 25

FIGURE 4. Disposal area at the end of construction in 1998

FIGURE 5. Jarofix stack in Summer 2000

FIGURE 6. Dumping of jarofix

FIGURE 7. Configuration of jarofix stack in December 1999

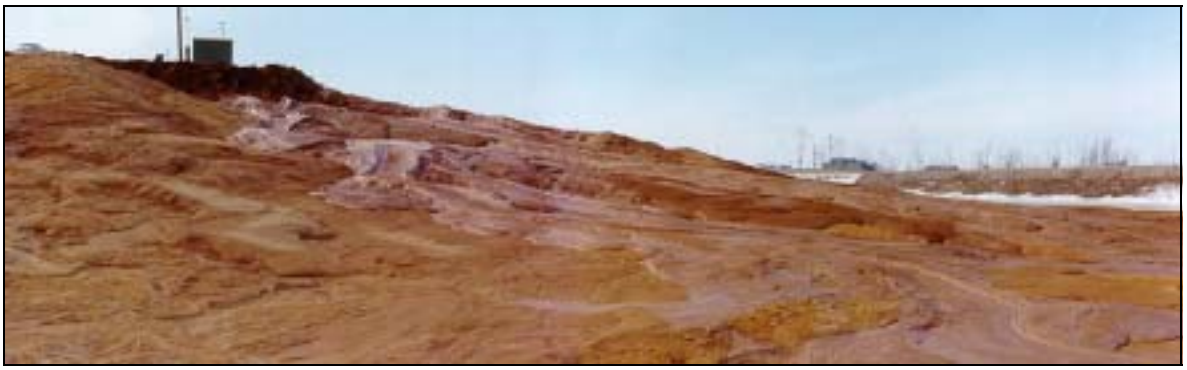

FIGURE 8. Typical jarofix depositional slope ±10%

FIGURE 9. Raising of starter dyke using jarofix as fill in 2000

FIGURE 10. Appearance of dyke raised in 2000 using jarofix as fill

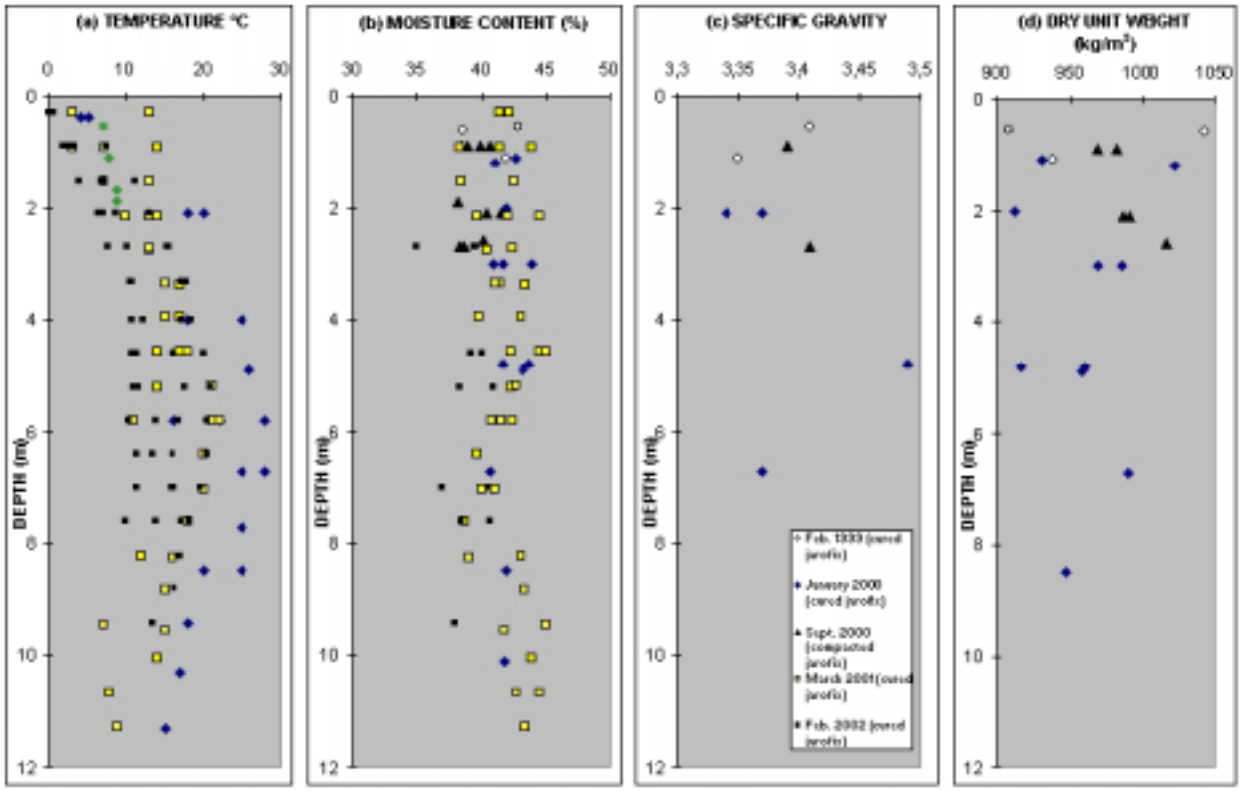

FIGURE 11. Physical properties of jarofix (part 1)

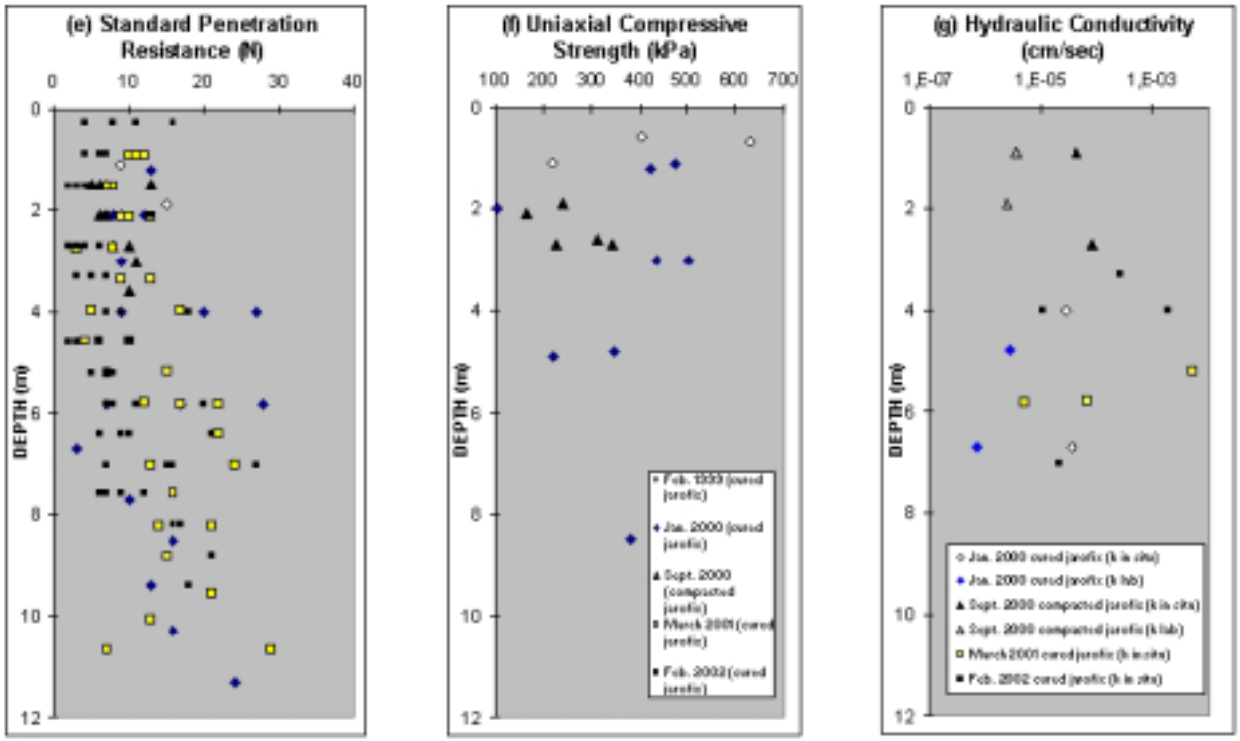

FIGURE 12. Physical properties of jarofix (part 2)

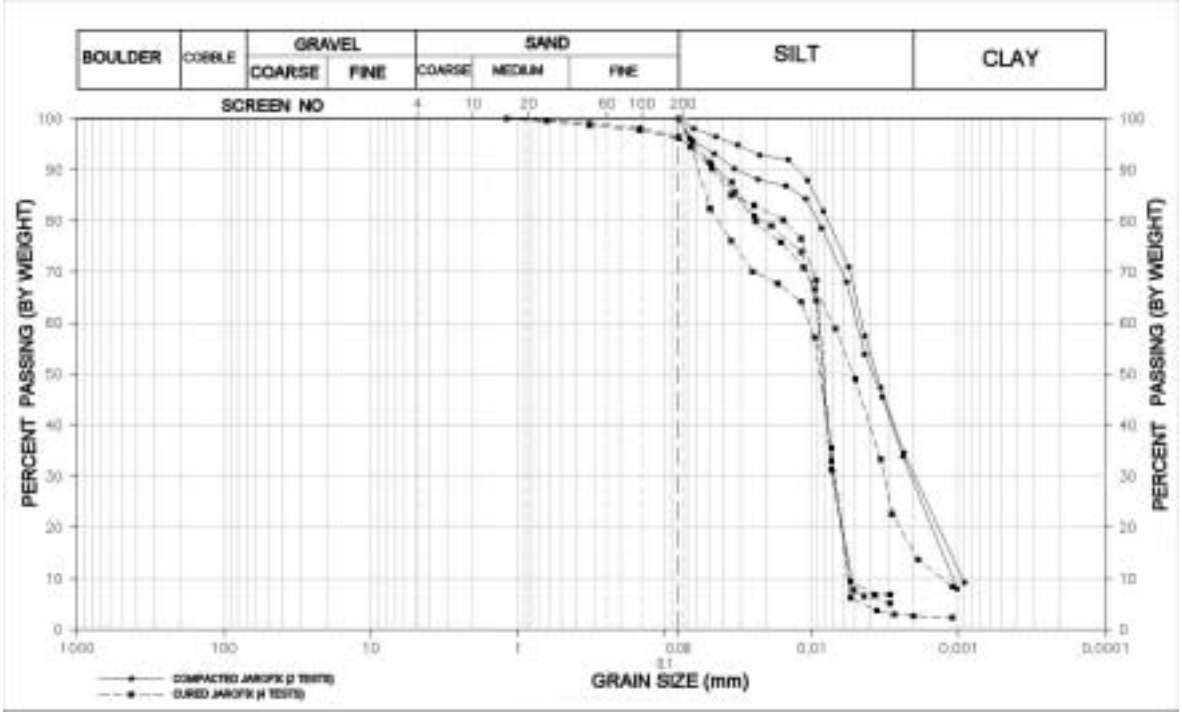

FIGURE 13. Grain size distribution of jarofix samples

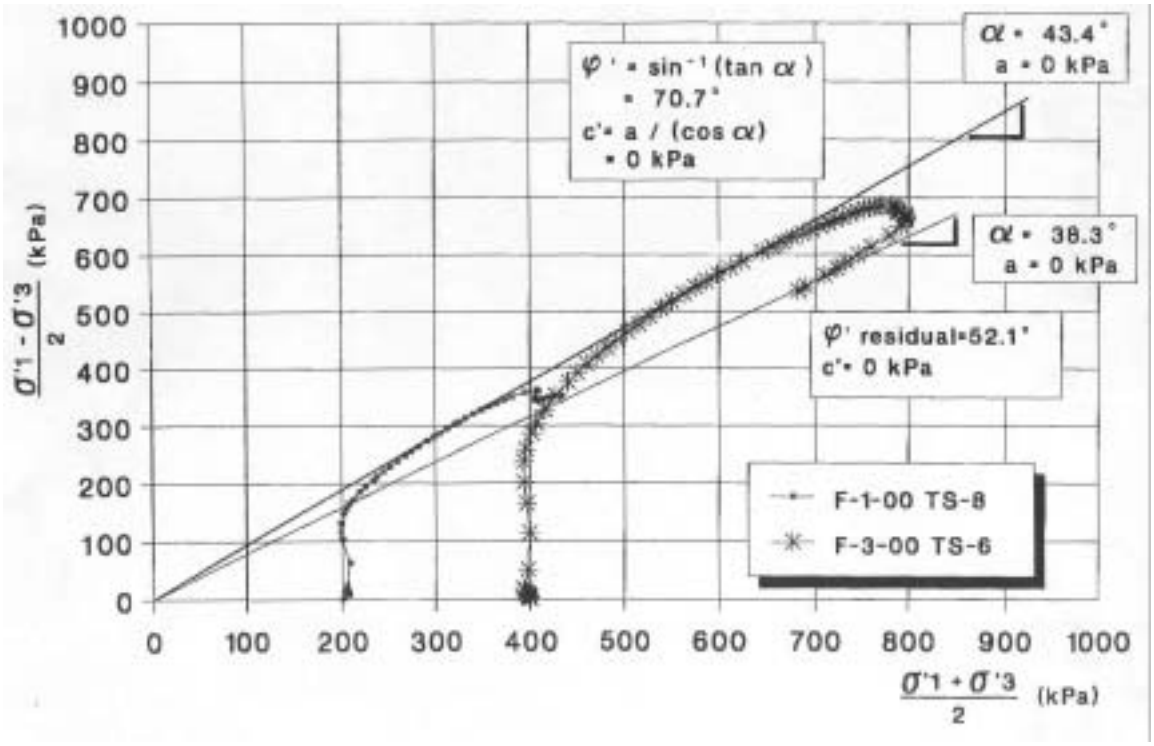

FIGURE 14. Results of CIU triaxial tests