Essential Readings in Light Metals: Alumina and Bauxite.
Edited by Don Donaldson and Benny E. Raahauge.
© 2013 The Minerals, Metals & Materials Society. Published 2013 by John Wiley & Sons, Inc.

FERROSILT (RED MUD): GEOTECHNICAL PROPERTIES AND SOIL MECHANICAL CONSIDERATIONS

F.C. Jenny

Abstract

The disposal of ferrosilt tailings creates problems because of the rather unusual geotechnical properties. Ferrosilt samples from three different bauxites were tested in connection with the alumina plant project in Wilhelmshaven (West Germany). The results of these laboratory tests explain various ferrosilt slides experienced during the past. Should ferrosilt be utilized for application where better physical qualities of the material are required it is possible to separate the coarser fraction from the finer fractions by using cyclons. The soil mechanical properties of the coarser fraction - called ferrosilt-sand - is of much better quality than the ferrosilt proper. On the other hand the quality of the finder fractions is not much inferior to the ferrosilt.

F.C. Jenny is Civil Engineer and Head of the Foundation Engineering Section of ALESA Alusuisse Engineering Ltd., Zurich, Switzerland.

Introduction

In connection with the alumina plant project in Wilhelmshaven (West Germany), studies for a ferrosilt deposit were made. The deposit would be close to the plant for the extension of the plant under certain conditions.

As there was only little knowledge about the geotechnical properties, many tests were performed in laboratories and in situ. The test-material was considered similar to the ferrosilt, which would be encountered in Wilhelmshaven.

At the time of sampling ferrosilt, the following mixture of bauxites was processed in the alumina plant:

Sierra Leone	52%	(trihydrate bauxite)
Jugoslavia (Mostar)	34%	(monohydrate bauxite)
Australia (Weipa)	17%	(90% trihydrate and 10% monohydrate bauxite)

During the investigations many problems arose because of the German term "Rotschlamm" (red mud). It gave to people unfamiliar with this expression the impression of a detrimental organic waste-material. That is one of the reasons why we decided to search for another term. The designation "FERROSILT" was chosen because of the high amount of red iron oxide (FERRO-) and the sieve analysis of the material which contains a high amount of silt fraction (-SILT).

Granulometry

The granulometry of the ferrosilt sample is shown in Figure 1. Striking is the high amount (40%) of the sand fraction. We expected that several geotechnical properties of ferrosilt-sand would be better than those of the composite ferrosilt. We decided therefore to separate ferrosilt-sand by cyclons and to extend the research work also to this material. The granulometry after separation shows an unsignificant silt and gravel fraction.

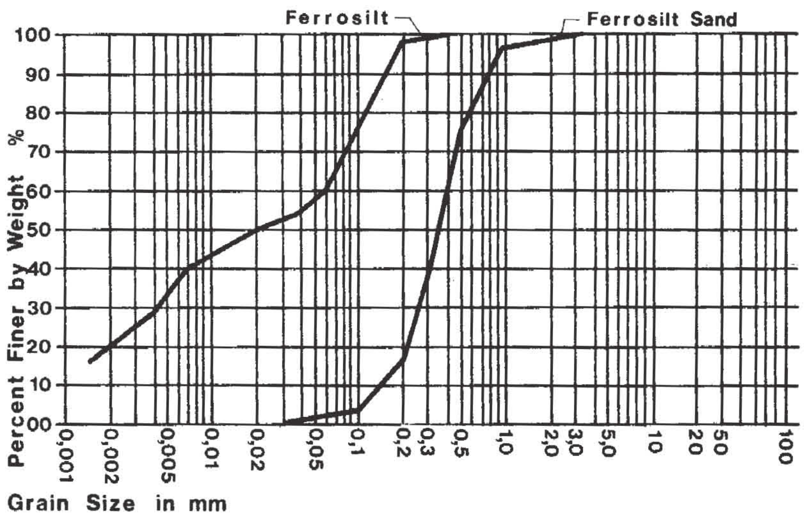

Figure 1: Granulometry of Ferrosilt and Ferrosilt-Sand

Plasticity

Ferrosilt has a low plasticity and is therefore specified as CL (clay, low plasticity) corresponding to the USCS-classification. Figure 2 shows an untreated and a neutralized (hydrochloric acid) ferrosilt in a plasticity chart. Although experiments have shown that for a less viscous slurry the neutralization reduces the viscosity to almost one third, it has little influence on the liquid and plastic limit.

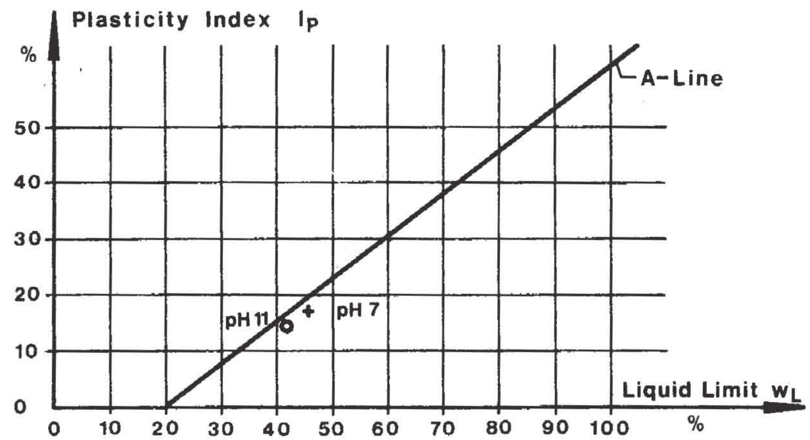

Figure 2: Casagrande Plasticity Chart

Character of Grain

Scanning electron micrographs of ferrosilt show that the clay-fraction consists of equidimensional polyedric grains with slightly rounded edges. The diameter of the majority of the grains is smaller than 0.5 μ. Real clay Minerals with a flat shape of grain, typical for clay, could hardly be found (Figure 7).

Ferrosilt-sand however consists partly of sharp edged grains and there are grains with a spongelike porous surface and slightly rounded edges (Figure 8).

Shear Strength

The granulometry and the behaviour of recently deposited ferrosilt suggest a small effective angle of internal friction. However, the equidimensional and mostly angular grains of clay, silt and sand fraction point to a great effective angle of internal friction.

The drained shear strength, which means the shear strength at a very slow strain was determined using the direct shear apparatus, ring shear apparatus and triaxial apparatus. The results of these tests correspond well. A maximum effective angle of internal friction (Ø') of 39° and a residual effective angle of 36° were measured. Considering the granulometry these values are astonishingly high.

The undrained shear strength and the residual undrained shear strength, which mean the shear strength at a fast strain, were measured with the vane apparatus. The vane shear shows a high sensitivity ration of approximately $S_t = 5$. Ferrosilt is therefore a sensitive material, which loses at a fast overstrain 80% of its undrained shear strength. The reason for this effect is the loose grain structure. It collapses in the zones of overstrain similar to the "domino" effect. After discharge of the excess pore water out of the zone of collapse the original shear strength can be reached again. Contrary to thixotropy this process can be repeated only a limited number of times. The return to its original shear strength is a typical feature of ferrosilt and contrary to the behaviour of most of the clay soils, for which flat clay minerals remain after failure aligned in the surface of sliding.

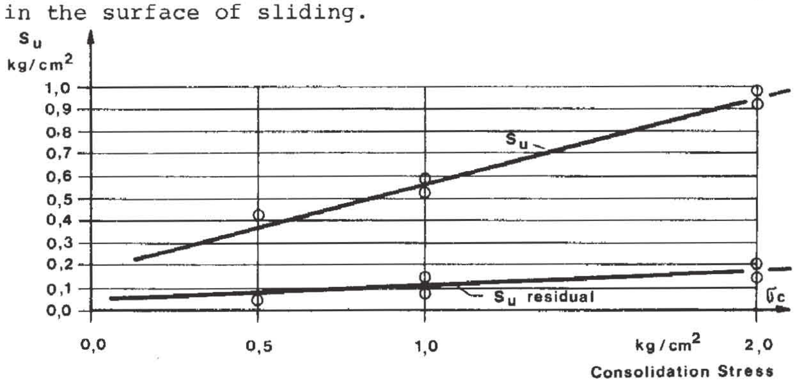

Figure 3: Ferrosilt, undrained shear strength

Figure 4 shows the effective angle of internal friction of ferrosilt-sand plotted against the porosity. The rather high porosity is a consequence of the uniformity of the grains (Figure 1). The effective angle of internal friction for ferrosilt-sand is rather high compared with usual sand.

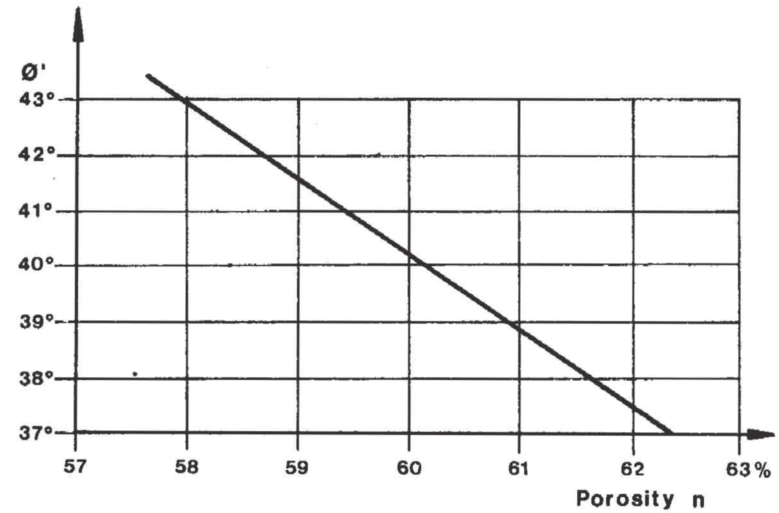

Figure 4: Ferrosilt-sand, effective angle of internal friction

Dehydration

The characteristics of dehydration by compression and dehydration by dessication were established through sedimentation and dessication tests, shrinkage limit and oedometer tests. In addition, capillary suction was tested by the pressure plates method.

Dessication of ferrosilt is very slow because of the low permeability of only $k = 10^{-7}$ cm/sec. The field tests (Zurich, Switzerland) have shown no dry-crust formation for water contents above the shrinkage limit. There had always been a sufficient water supply from deeper stratums. During summertime, the increase of water content was rather uniform and reached $\Delta w = 2.65\%$ per 10 cm of depth. During wintertime however, there was almost no dessication. The water content compensated down to w = 0% per 10 cm of depth.

The reduction of water content by dessication enlarges suction or negative pressure of pore water (Figure 5). As reaction a growing pressure compacts the grain structure. This shrinking process continues down to the water content of the shrinkage limit of w = 37.5% where the negative pressure of pore water reaches approximately 8 kg/cm2. Under this condition, the unit weight of ferrosilt is at its maximum with γ = 1.955 t/m3. Below the shrinkage limit the unit dry weight remains constant. whereas the unit weight decreases because the pores start to be unsaturated (Figure 6).

The dessication effect drains a stratum of probably at least two to three meters.

Higher unit dry weights of a saturated ferrosilt than 1.42 t/m3 are only achievable at a compressive stress above 8 kg/cm2 or through mechanical compaction of an unsaturated ferrosilt.

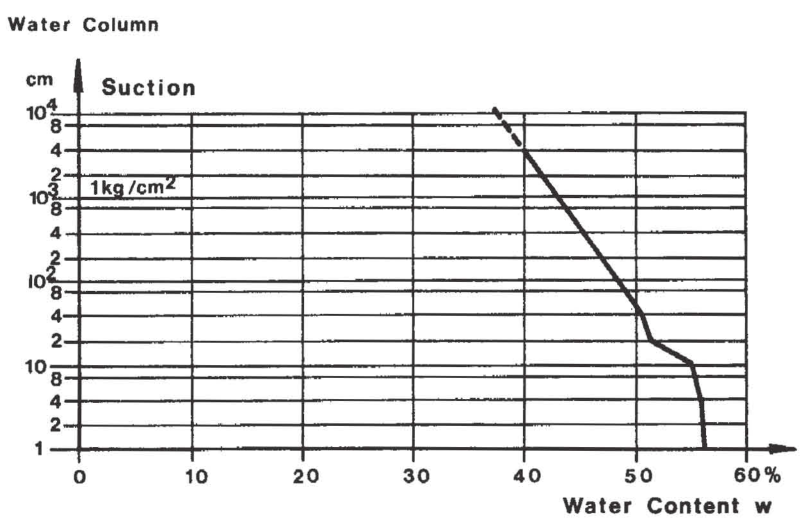

Figure 5: Suction of Ferrosilt

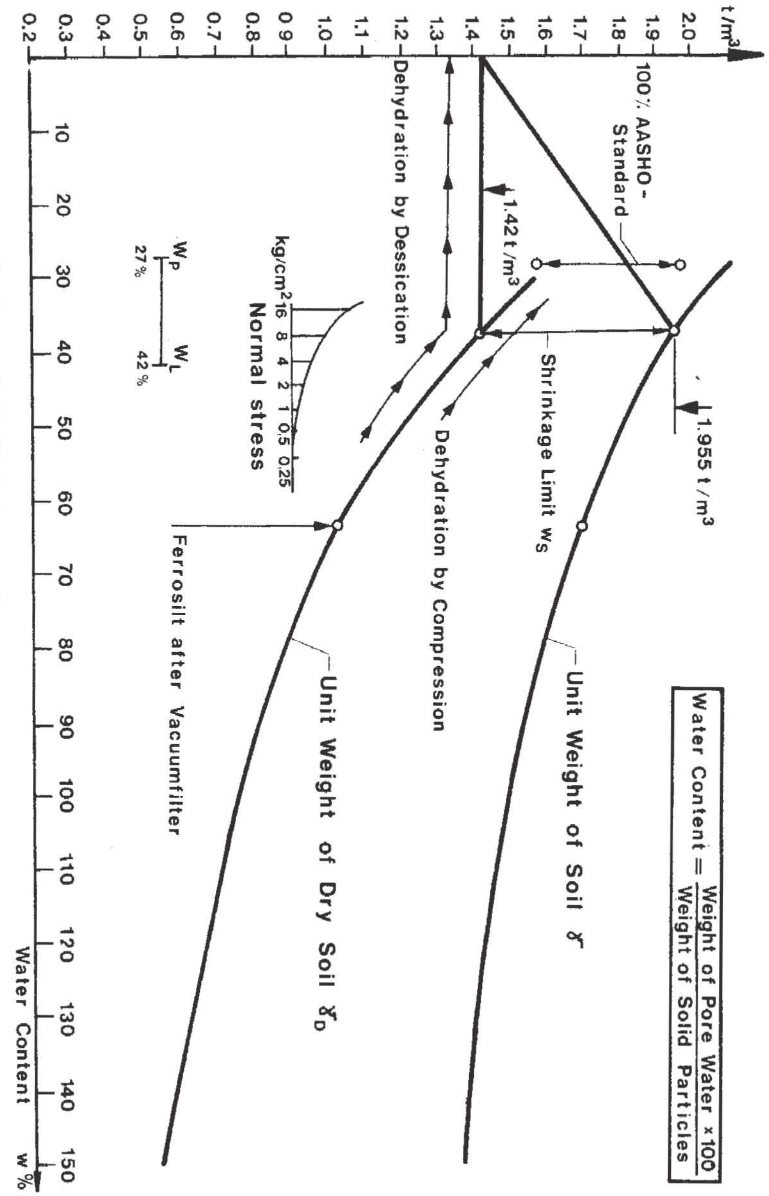

Fig. 6 Unit Weight of Ferrosilt

Soil Mechanical Considerations

The investigated ferrosilt contained a large amount of sand, which could be easily separated by cyclons. Ferrosilt-sand has better soil mechanical properties than ferrosilt and can be used where higher physical qualities are required, e.g. to errect storage dams for ferrosilt deposits, as top layer of fills, etc.

The high effective angle of internal friction of a sufficiently dehydrated ferrosilt is responsible for a high shear strength. Ferrosilt is a sensitive material and loses most of its shear strength if overloaded. Several ferrosilt-slides from 10'000 tons to 400'000 tons experienced during the past years could be explained as a collapse of the grain structure.

Dessication of ferrosilt deposits is very effective to compact layers of some 2 to 3 meters. Ferrosilt has to be dried to the shrinkage limit only because the unit dry weight is at its maximum at this water content (Figure 6). The dessication is much reduced at water contents below the shrinkage limit because the pores become increasingly unsaturated. This reduces the heat transfer, evaporation and permeability.

Conclusion

Ferrosilt and in particular ferrosilt-sand are soil materials with acceptable properties as long as the particular soil-mechanical behaviour is considered. There is no reason at this stage not to use it as subbase in the area proposed for the extension of the alumina plant complex at Wilhelmshaven. The whole area of the proposed industrial site at Wilhelmshaven is reclaimed from the shallow water along the seashore and filled with dragged material. The subsoil consists of a recent and rather compressible strata of sand, silt and clay. The groundwater of the reclaimed area is almost at surface level depending on the seasons and the tides. For the founding of heavy loads or structures which are sensitive to settlements, piles or other special founding technics, as executed for the chemical plant of "Atlantik", a subsidiary company of our Corporation,in that area would be required in any case. A ferrosilt fill has the disadvantage that the piles, where required, would have longer pile-shafts, on the other hand, it has the big advantage that the site level would be substantially above the groundwater level, which means that most of the structures could be executed without special dewatering methods.

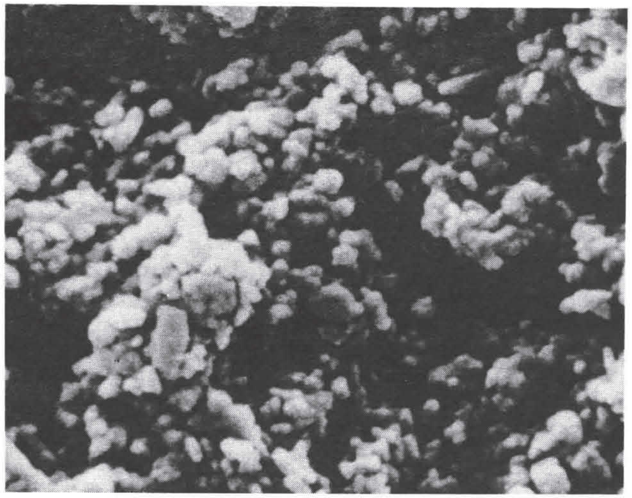

Figure 7: Scanning electron micrograph of Ferrosilt,
Magnification 22'500x

Figure 8: Ferrosilt-sand, Magnification 11x