The University of New Mexico

New Mexico Engineering Research Institute
Albuquerque, NM 87131-1376
USA

Date: July 19,1996

To: Margaret Chu, MS-1335 (6801)

JW Berglund. Jonathan Myers Larry R. Lenke

From: J. W. Berglund 6849, NMERI; J. Myers, IT Corp; L.R. Lenke, NMERI

Subject: Estimate of the Tensile Strength of Degraded Waste for use in Solids Blowout

A value of 1 psi (6895 Pa) was chosen to represent the tensile strength of decomposed waste for the purpose of computing blowout spall releases resulting from a drillbit intrusion into a pressurized waste panel. Such spall releases occur only if the gas pressure exceeds the hydrostatic drilling mud pressure of approximately 8 MPa. A chemical reaction between the waste and brine from the surroundings is necessary to generate the gas to raise the waste pore pressure to these levels. Without brine inflow, little gas will be generated and waste decomposition will be negligible. Thus the phenomenon of blowout spall requires both brine inflow and waste decomposition.

The future state of decomposed waste is both time dependent and unknowable. Therefore a decomposed state consisting of graded granular materials is assumed. This is consistent with the granular nature of decomposed geologic materials and corresponds to an end state of the decomposition process. Such materials lack significant composite strength from the interleaving of components and is the state found to be most troublesome in oil production where sand is produced from poorly consolidated sand layers. The value of 1 psi chosen for cementation strength for the decomposed waste can be reasonably expected to be conservative, i.e. lower than those data values found for many weak materials that are naturally occurring or that have been manufactured. Data to support this value can be found in the literature for the strengths of soils, laboratory produced mixtures of salt and clay, and mixtures of various materials with MgO; the latter added as a backfill material to the waste. A discussion of these data sources follows.

Soil Data

Tensile strengths for several compacted, cohesive soils e.g. Vicksburg buckshot clay (CH), Vicksburg lean clay (CL), and a sandy clay mixture from De Gray dam (SC) were measured using hollow cylinder tests and indirect tensile tests in Al-Hussaini (1981). The samples were prepared to optimum water content compacted and tested. Results for the hollow cylinder tests are shown in Table 1. All exceed 1 psi by factors of approximately 3 to 8 times. Similar results were obtained from the indirect tensile tests.

Table 1 Hollow Cylinder Tests

Material type	Tensile Strength (psi)
CL-1	2.95
CL-2	3.90
CL-3	3.93
CH-1	7.93
CH-2	7.41
CH-3	7.99
SC-1	5.90
SC-2	5.38
SC-3	4.49
CH-4	6.46
CH-5	6.12
CH-6	6.52

Direct tensile tests on simulated waste materials were also conducted by Berglund and Lenke, 1995, p13-14. Various mixtures of partially saturated silica sand and kaolin clay were used to represent the waste. The clay represented a natural material that was chosen to be a close surrogate to partially decomposed cellulosics and plastics. The sand represented the particulate structure expected of magnetite or other products of the iron corrosion reaction. The mixture was 85% sand and 15% clay, a ratio similar to the ratio of decomposition products anticipated for some waste conditions. The tensile strength measured in these experiments was 2.9 ± 1.4 psi. A second indirect method of measuring tensile strength in the Berglund, Lenke study implied an even higher tensile strength value of 4.3 ± 1 psi.

The tensile strength of the above materials (Al-Hussaini 1981, Berglund and Lenke 1995) occurred in the absence of any additional cementation process which would tend to increase these measured tensile strengths.

Salt Mixture Data

Some brine is expected to exist within the waste panels after closure of the facility. The most likely source is brine of Permian age that was trapped in the Salado formation at the time of evaporite deposition. Limited brine occurrences in the WIPP underground have been extensively sampled and analyzed, and the composition of Salado brine is well understood. These brines contain approximately 374 grams of dissolved constituents per liter and are in chemical equilibrium with halite ($NaCl$) anhydrite ($CaSO_4$), and magnesite ($MgCO_3$).

The removal of even a small amount of water from this brine by evaporation or chemical reaction will result in the precipitation of salts which will act as a cementation agent. One such chemical reaction that is anticipated to occur is the anoxic corrosion of iron and ferrous alloys, which constitute a significant percentage of the waste inventory in the form of steel drums and boxes, contaminated tools and sheet metal, etc.

The reaction of brine with metal will consume H_2O and generate hydrogen and some corrosion product. A typical anoxic reaction might be

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2$$

Consumption of H_2O by corrosion reactions will cause the mass of dissolved solids in the brine to precipitate as a series of evaporite minerals in close proximity to the surface of the corroding metals forming encrustations which tend to cement the waste. Simulation of the removal of H_2O from one kg of Salado brine using the EQ6 code (Wolery T.J., and S.A. Daveler, 1992) yielded 534 grams of precipitates (anhydrite, bischofite, carnallite, halite, kieserite, and magnesite). The mass is greater than the mass of dissolved solids because of the hydrous nature of some of the precipitates.

Evidence for this process in the WIPP underground could be seen at the close of heated brine inflow experiments performed by SNL a number of years ago. In these experiments, a metal canister containing an electrical heater was placed in a vertical hole excavated in the floor of a room in the northern experimental area. The top of the hole was sealed, and anhydrous nitrogen was circulated within the annulus between the canister and the hole. Small amounts of brine flowed toward the hole in response to the pressure and temperature gradients surrounding the heated hole, and evaporated as it approached the canister. The nitrogen acted as a carrier gas for water vapor and was allowed to exit the hole where it flowed into an apparatus where the water vapor was extracted and quantified.

It was found at the close of the experiment that the canister has become firmly cemented in the hole by the precipitation of salts from the evaporating brine within the annulus. A work-over rig had to be employed to extract the canister from the hole. The removal of water from brine by any process, be it evaporation or corrosion reactions, will produce the same cementation effect by the precipitation of minerals at the site of water removal. This cementation will act to increase the strength of the waste.

A number of strength tests were done for consolidated crushed WIPP salt and mixtures of WIPP salt and bentonite (70 and 30% respectively) (Finley, 1996). Finley's memorandum presents estimates of tensile strengths of clay/salt mixtures based on experimental observations of unconfined compressive strengths and the extended Griffith criterion for tensile failure (Jaeger and Cook, 1976). These estimates are for 30/70 percent bentonite/salt mixtures at fractional densities of 0.83 to 0.88. Finley estimates tensile strengths between 10 and 100 psi.

The WIPP waste stream upon creep closure and subsequent brine saturation will consist of approximately 1350 kg of waste solids (assumed average solid density of the waste was taken as 2700 kg/m^3) and 188 kg of precipitated salt (based on dissolved salt solids of 374 gram/liter cited above) per cubic meter of repository. These numbers are based on a typical closure porosity of 0.5 (final room height of 1.2 m). The gravimetric ratio of salt precipitate to solid waste for these conditions is 0.14. This is a factor of 5 less than the ratio cited by Finley. Using this factor, it is not unreasonable to expect tensile strengths between 2 and 20 psi.

Effects of MgO on Strength

An additional process affecting the strength of the waste/backfill composite material is the chemical interactions that will occur between Salado brine and the MgO backfill. These interactions were simulated using the EQ3/6 code (Wolery, 1992; and Wolery T.J., and Daveler, 1992) with the Pitzer activity coefficient option and Harvie-Moller-Weare database. Five moles of MgO were reacted with one kilogram of Salado brine in a series of small steps. The dissolution of the five moles (202 grams) of MgO into the brine resulted in the precipitation of a total of 507 grams of minerals and the incorporation of 20 percent of the original kg of brine as water of hydration within the precipitates. These precipitates include Mg-oxychloride (63% by mass) and brucite (31% by mass), with minor amounts of anhydrite, halite, and magnesite. Similar results were found by Wang, 1996.

The two dominant precipitates (Mg-oxychloride and brucite) are the key phases in Sorel cement. In fact, Sorel cement is commercially prepared by mixing a magnesium-chloride brine (quite similar to Salado brine) with MgO. Sorel cement is known to have uniaxial compressive strengths in the range of 7,000 to 10,000 psi (Sax and Lewis, 1987). This range is equivalent to tensile strengths of from 490 to 700 psi (Dunham C.W., 1966). Thus the use of an MgO backfill will result in the cementation and strengthening of the waste/backfill composite material as long as sufficient brine is available for the chemical reactions to occur.

Conclusions

While tests to actually measure the binding forces between particles of simulated waste have not been performed, there are data available from several independent sources that suggest that the selection of 1 psi is well below the actual value of tensile strength that can be reasonably expected for decomposed waste. The tensile data presented for several soils without chemically generated salt precipitates exceed 1 psi by factors generally greater than 3. Estimated tensile strengths of consolidated halite-bentonite mixtures exceed 1 psi by factors of ten or more. The role of precipitated salts from anoxic reactions of brine with waste metals is expected to be similar though perhaps not as intense. MgO is added to the waste as a backfill material in large volumes. The reaction products of MgO plus brine are the principal components of Sorel cement which attains high compressive strengths and predicted tensile strengths of 490 to 700 psi.

References

Al-Hussaini, M. (1981), *Tensile Properties of Compacted Soils,* Laboratory Shear Strength of Soil, ASTM STP 740, R. N. Yong and F. C. Townsend, Eds., American Society for Testing Materials, pp.207-225.

Berglund, J.W., and Lenke, L.R., 1995, *One Dimensional Experiments of Gas Induced Spall,* NMERI 1995/3, prepared for Sandia National Laboratories, New Mexico Engineering Research Institute, University of New Mexico, Albuquerque, NM, February 1995 WPO# 27589.

Dunham C.W., 1966, *The Theory and Practice of Reinforced Concrete*, McGraw -Hill, New York, p 36.

Finley, R.E. May 3, 1996 Memorandum to D.R. Anderson and M.S.Y. Chu, Subject: Tensile Strength of Consolidated Crushed Salt

Jaeger, J.C. and N.G.W. Cook, 1979, *Fundamentals of Rock Mechanics*, 3rd Edition, Chapman and Hall, London

Sax, N. I, and R. J. Lewis, 1987, Hawleys Condensed Chemical Dictionary, Eleventh Edition, Van Nostrand Reinhold, New York.

Wang Y., 1996, Memorandum to Malcolm Siegel, March 18, 1996, Subject: Define Chemical Conditions for FMT Actinide Solubility Calculations SWCF-A, WBS 1.1.09.1.1(BC);QA

Wolery T.J., 1992, EQ3NR, *A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations*: Theoretical Manual, Users Guide, and Related Documentation (Version 7.0). Lawrence Livermore Laboratory, Livermore California.

Wolery T.J., and S.A. Daveler, 1992, EQ6, *A Computer Program for Reaction Path Modeling of Aqueous Geochemical Systems*: Theoretical Manual, Users Guide, and Related Documentation (Version 7.0). Lawrence Livermore Laboratory, Livermore California.

cc:

MS 1330 SWCF-A:1.1.01.2.7:DRM:QA:Waste Strength, TD