A Red Road in Jamaica

A mixture of lime, gypsum, red mud, and terra rossa is shown to be a viable product for secondary road repair

by Peter Claisse and Richard Annells

Jamaica has absolutely no fossil fuel resources: no oil, no gas, and no coal. The imported fuel used to produce cement is a drain on the economy and infrastructure development, and repair is being severely limited by material costs. Jamaica does, however, have excellent mineral resources, including natural pozzolans and bauxite for alumina production.

Red mud is the waste produced from bauxite processing. A typical plant produces one to two times as much red mud as alumina and this takes up land area that can neither be built on nor farmed, even when dry. Jamaica has five bauxite mines of which four have closed for production but the red mud impoundments (Fig. 1) remain as scars on the beautiful landscape. There is a large body of research indicating that this material can be used to make concrete.[1] The aim of the project presented in this article was to use it to develop a low-cost repair material for the potholes and service trenches in the roads in Jamaica.

The specific objectives were to develop new concrete mixtures using the same cementitious material (binder) blend for two applications:

- A semi-dry concrete mixture for filling potholes in parochial roads. The ideal material would be made with locally available aggregate, be suitable for placement using roller compaction to take early traffic loading, and would remain in position many times longer than current repairs carried out with unbound aggregate (which is ejected from the potholes during the first heavy rainfall); and
- A flowable grout mixture for backfilling trench excavations crossing roadways. The ideal material would be a self-consolidating, controlled low-strength material (CLSM) that would harden rapidly to expedite reopening for traffic but remain soft enough (compressive strength of 1 to 2 MPa [145 to 290 psi]) to be re-excavated if needed.

The project was not intended to develop material suitable for surface layers of high-speed roads or for structures such as beams or columns.

Fig. 1: An impoundment of red mud in Jamaica

Laboratory Mixtures

The mixture designs were developed during an intensive 4-week program starting with 65 binder paste mixtures made in plastic cups that were inspected for setting time, estimated strength, and stability in water. Ten binder mixtures were then taken forward for testing for mortar strength in 50 mm (2 in.) cubes. One binder blend was selected for concrete strength testing in 100 mm (4 in.) cubes and the field trial, which took place 4 weeks later.

Mortar tests

Following the results of Yang and Xiao[1] and the observations from the paste mixtures, 50 mm (2 in.) mortar cubes were made using binder blends with five potential components: lime—a primary material purchased from local supplier; gypsum—a waste product from a disused quarry near Kingston; pozzolan—a pale gray, friable acid-intermediate volcanic rock; terra rossa—red clay soil from the St. Catherine parish; and red mud (Table 1).

Mortar samples had a sand-binder ratio of 2 (by mass) and were prepared using a water-binder ratio (*w/b*) that was

Table 1:
Strength test results for mortar mixtures

Batch No.	*w/b*	Binder components, %					Average 3-day strength, MPa (psi)	Average 32-day strength, MPa (psi)	Strength gain, %
		Lime	Gypsum	Pozzolan	Terra rossa	Red mud			
1	0.71	10	20	0	35	35	0.45 (70)	0.75 (110)	67
2	0.74	10	5	0	42	42	0.58 (80)	—	—
3	0.71	10	20	35	0	35	0.33 (50)	1.02 (150)	205
4	0.74	10	5	42	0	42	0.61 (90)	1.23 (180)	102
5	0.74	10	10	0	40	40	0.95 (140)	1.13 (160)	18
6	0.76	5	5	0	45	45	0.25 (40)	0.31 (50)	22
7	0.74	10	10	0	20	60	1.11 (160)	1.42 (210)	27
8	0.80	5	5	0	22	67	0.26 (40)	0.27 (40)	5
9	0.67	10	10	0	60	20	0.90 (130)	1.03 (150)	14
10	0.69	5	5	0	67	22	0.38 (60)	0.53 (80)	41

Note: Mixtures comprised two parts sand for one part cementitious material and were tested using 50 mm (2 in.) cubes. Mixture 7 exhibited the highest strength.

sufficient to give a flowable mixture which could be used for trench filling. Based on the 3-day strength results:

- Comparing Mixtures 1, 2, and 5 shows that mixtures with equal mass of gypsum and lime perform best;
- Comparing Mixtures 1 and 3, and also comparing Mixtures 2 and 4 shows that mixtures with either the pozzolan or the terra rossa have similar performance; and
- Comparing Mixture 5 with 7 and 9, and also comparing Mixture 6 with 8 and 10 shows that it is better to have more red mud than terra rossa.

All the results show that 5% lime is insufficient.

The 32-day strength results (Table 1) confirmed that Mixture 7 was strongest, while mixtures with the gray volcanic rock (Mixtures 3 and 4) had considerable strength gains from 3 to 32 days. However, as recommended by Chandra,[2] a minimum 20% terra rossa content (Mixture 7) was selected to counteract any long-term loss of strength.

Concrete tests

A concrete mixture was evaluated using 100 mm (4 in.) cubes. The binder proportions matched those of Mixture 7 from the mortar tests (refer to Table 1). The semi-dry mixture had a 1:2:4 binder:sand:coarse aggregate proportion and was produced using a *w/b* of 0.57. Two batches of cubes were made—the first comprised materials delivered for the laboratory work and the second comprised materials from the bulk deliveries for the site trial.

For the first batch, the compressive strengths measured at 3 and 29 days were 6.5 and 6.8 MPa (940 and 990 psi), respectively. For the second batch, strength values at 3 and 20 days were 4.6 and 6.5 MPa (670 and 940 psi), respectively. It should be mentioned that compacting a semi-dry mixture into cube molds is not easy and some variability in the test results can be expected. For example, Ganjian et al.[3] found that when testing roller-compacted core samples from the semi-dry paste layer in the trial road at King's Mill Hospital site, cores gave double the strength of the site cube samples.

Findings

The mixture that has been developed is a "two-stage" blend which relies on the red mud-lime reaction for early strength and then the pozzolanic reaction of the terra rossa to give longer-term strength and counteract the strength loss identified by Chandra[2]. It is recommended that this concept (which was also used by Yang and Xiao[1]) is adopted in all future mixtures.

As for the gypsum used in the proposed mixture, the material was highly weathered, dirty, and poorly graded with not enough hemihydrate to react and give false set. Therefore, even at 10% gypsum in the mixture (much greater than 3% clean and well-grounded reactive gypsum used by Yang and Xiao[1]), we don't expect it to cause any long-term expansion issues in the chosen application.

For the trench backfill application, it was necessary to have a mixture with sufficient strength after 12 hours to give the same performance as an aggregate backfill and not to subsequently settle (as occurs in so many trench reinstatements). A limited long-term strength to permit re-excavation was also required. The strength of this mixture would be far lower than the semi-dry concrete because of the far higher *w/b* required to make it flow (the flowable mixture used in the 50 mm [2 in.] cubes had a *w/b* of 0.74 while the semi-dry concrete mixture had *w/b* of 0.57). The 32-day strength of Mixture 7 mortar cubes was

Fig. 2: Discharging a gauge box into the mixer

Fig. 3: Roller compacting the mixture

1.42 MPa (210 psi), which should be suitable for this application. If lower strength is required, more water and fine aggregate could be added to reduce it.

Field Trial

A site trial was carried out on a 40 m (131 ft) long road at the side of the laboratory on the University of the West Indies campus. The semi-dry roller-compacted mixture was used because this would permit early loading when used in potholes. The mixing was carried out in 1/4 yd^3 (190 L) mixers with all the materials being measured into them with gauge boxes (Fig. 2). It was then placed by hand and roller-compacted (Fig. 3 and 4).

Test cubes taken from the site-mixed concrete only achieved about 2 MPa (290 psi) at 15 days. It is believed that this was because the site mixing of the binder was inadequate and it is proposed that all future work should use a preblended cementitious material.

Fig. 4: The completed road

Proposed Construction Methods

Based on the experience from the site trial and previous work, we believe that the best route to commercial exploitation is with a preblended powder mixture of lime, gypsum, red mud, and terra rossa. The binder would be suitable for production of the low-strength mixtures used for filling a pothole. The complete procedure would be:

- Red mud is dried naturally in a covered area;
- Terra rossa, lime, and waste gypsum are manually mixed with the dried red mud;
- Lumps are broken up to form a pink-gray powder that is bagged and sold as a commercial product;
- The road repair crew manually mixes the binder with water and the same aggregate that they normally use; and
- They then place and compact the mixture using the same roller they normally use to compact unbound aggregate.

The repair needs to be protected from rain only for a few hours. It can take light traffic immediately, but tarmac surfacing may be applied in due course if funds permit.

A trial was carried out on some potholes on the campus roads. The traffic was only diverted while the potholes were filled with the mixture. They were then immediately subjected to continuous traffic loading—no other compaction was used. Within 4 hours of placement, there was very heavy rainfall. Despite these adverse conditions, the repair remained in place. Some surface laitance was lost because of the action of traffic during the rainfall but no significant loss of material occurred.

Commercial Application in Jamaica

Readers of the academic literature on concrete will be aware that there is a vast body of reported research on the use of waste minerals to replace cement in concrete. While topics of this type are popular for postgraduate degree projects, commercial exploitation of replacement technologies is very limited. This project was therefore designed from the outset to encourage commercial application.

The preblended powder can be made manually with minimal plant use. Because it has a labor-intensive economy, Jamaica is a good place to exploit the material. Also, the lack of the need for significant capital investment will greatly reduce the commercial risk.

We have calculated that both the cost and environmental impact of the primary materials in the proposed cementitious material are just 7% of those for conventional cement.

The potholes in Jamaica's rural roads damage vehicles and cause accidents where drivers attempt to avoid them. It is hoped that this project will not only create jobs in the economy but also make the parochial roads safer.

Relevance to Other Countries

In the United Kingdom or the United States, a significant investment would be needed to bring a low-strength cementitious material to market. However, the level of research and commercial interest indicate that these mixtures may soon be produced on a large scale in China. The essential novelty of the concept in this project is the proposal to produce a low-strength cement to make low-strength concrete (rather than using normal cement and in a concrete with high water content or foam, for example). This concept is used in hydraulically bound materials in road bases, but these rely on a cementitious component which is developed and mixed for a specific project.

Fortunately in Jamaica, there is never any frost. The site trial road and any pothole repairs would probably break up rapidly in the event of any significant freezing. However, the low modulus of elasticity of this mixture might permit the formulation of mixtures that behave like pervious concrete and do not fail.

Readers of *Concrete International* will be aware of the environmental impact of concrete production. The 4 Gt (4 billion tonnes) of cement produced annually releases 3 Gt of CO_2 into the atmosphere. This is approximately 7% of the global CO_2 total—more than aircraft. We hope that this work will make a small contribution to reducing this while at the same time increasing concrete production to build and repair the infrastructure that is needed.

Summary

There is great potential for the use of a novel low-cost concrete in the repair of rural roads. While high levels of cement replacements are the most promising way forward to make low-cost concrete, a low-strength cement can be produced to make low-strength concrete.

A semi-dry mixture is proposed for potholes. A concrete mixture with a binder comprising 10% lime, 10% gypsum, 20% terra rosa, and 60% red mud has been tested in a site trial and gave strengths over 5 MPa (730 psi) at 3 days for laboratory samples. We believe that preblending the cementitious powder is essential to achieve reliable quality for the mixture and could provide jobs for small businesses.

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Selected for reader interest by the editors.

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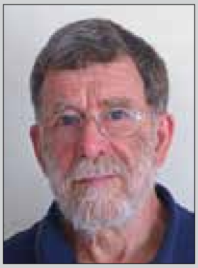

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