CHAPTER 5 SUMMARY AND CONCLUSION

5.1 WASTE AUDIT

According to the survey carried out on the weight loss from each step, for small pieces, grinding process (including the external, internal and final grinding) contributes the highest amount of brake lining dust (10.64% - 13.03%). On the other hand, cutting of billet (brake lining in bigger size) into smaller sizes contributes the greatest amount of brake lining dust, which was approximately 30%. This is followed by drilling (2.17% - 6.87%) and chamfering (0.49% - 1.07%).

5.2 WASTE RECOVERY

Based on the results obtained from the performance test, the brake lining sample with 10% reclaimed brake lining dust shows greater potential for recycling than the sample with 5% brake lining dust. The former gave good results in all the performance characteristics. In contrast, the sample made from 5% brake lining dust did not gave satisfactory results and hence was not acceptable for recycling purpose.

However, more research needs to be carried out to investigate the possibility for higher percentage of brake lining dust recovery.

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5.3 SOLIDIFICATION / STABILIZATION

5.3.1 Results of TCLP

Percentage of Leachable Fraction

The TCLP results revealed that cement was able to immobilize the heavy metals to certain extent, depending on the cement loading. Among the heavy metals of concern, Ba contributed the highest percentage of leachable fraction and it showed a descending trend as the cement loading declined, ranging from 34.76% - 51.1%. This could be due to the presence of barium hydroxide in both brake lining dust and the cement itself. On the other hand, the percentage of leachable fraction of the rest of the heavy metals (Zn, Cr, Pb, Cu and Fe) were comparatively lower, which was in the range of 15.69% - 33.82%.

Higher percentage of leachable fractions were observed at higher waste loading, thus the high loading of waste retarded the efficiency of cement binder to immobilize the heavy metals.

The results also revealed that the addition of activated carbon to cement reduced the leaching of the heavy metals considerably as compared to those treated by cement alone. The greatest reduction of 15% - 24% was observed in the leachable fraction of Ba, followed by Zn and Pb (7 - 9%), Fe (6 - 8%) and Cu and Cr (4 - 5%).

As expected, the replacement of polymeric resins as binder further reduced the heavy metals leachability. Polymal and Hetron reduced the percentage of leachable fraction of all metals of concern to less than 15% and 16% respectively. Retention efficiency improved as higher resin loading was used. It was also observed that at the same loading, the amount of initiator added to both Polymal and Hetron did not significantly affect the percentage of leachable fraction of the solidified specimens.

The pH of TCLP Extract

The final pH of the TCLP extract for untreated dust, cement and cement-based treated samples were basic, indicating an appreciable acid neutralization (buffering) capacity in the samples that offset the initial pH of the TCLP extraction fluid. In particular, the final pH of TCLP extract for the cement-based treated samples, increased drastically from the initial pH of 4.91 - 4.94 to 10.49 - 11.87. The pH value showed a descending trend in both cement and cement with activated carbon treated TCLP extract as the cement loading decreased. However, only a slight increase in pH was observed in the polymeric resin treated TCLP extract and the pH value was consistent, in the range of 5.08 - 5.19, regardless of the amount of resin used.

Effects of Final pH of TCLP Extract on Percentage of Leachable Fraction

A relationship between the final pH of TCLP extract and the percentage of leachable fraction for the heavy metals of concern (except Ba) was observed in both cement and cement with activated carbon treated TCLP extract, whereby the percentage of leachable fraction decreased as the pH decreased from 12.36 to 10.94. This is consistent with previous studies where metal hydroxides normally have minimum solubility in the range of pH 7.5 - 11. However the amphoteric nature of the heavy metals (Cr, Pb, Zn, Cu and Fe) exhibit higher solubility at both low and high pH.

On the other hand, the percentage of leachable fraction of the heavy metals in both Polymal and Hetron TCLP extract showed little or no apparent pH dependence.

5.3.2 Results of ANS 16.1 (Modified)

Leaching Rate

Rapid loss of heavy metals was observed on the first day of the leaching test, this was probably due to the surface wash off. For the cement-based treated samples, Ba showed the highest leaching rate among the heavy metals studied, and the leaching rate slowed down as time progressed. Lower leaching rate was observed as the cement loading decreased. In contrast, the leaching rate of other heavy metals (Zn, Cr, Pb, Cu and Fe) increased as the binder loading decreased.

The heavy metals in cement with activated carbon treated samples demonstrated similar leaching trend but at the lower leaching rate. Ba showed the highest leaching rate, followed by Zn and Pb, whereas the leaching rate of Cr, Cu and Fe were lesser as compared to Ba, Zn and Pb and approximately the same among them.

In polymeric resin (Polymal and Hetron) treated samples, only the leaching of Zn, Ba and Pb can be detected, whereas Cr, Cu and Fe were below detection limit for all the ratios investigated, within the 28 days leaching period. A comparatively higher leaching rate was observed in Hetron treated samples.

The three detected heavy metals demonstrated a descending leaching rate as the leaching time progressed but at a lower leaching rate as compared to the cement-based treated samples. Zn exhibited the highest leaching rate, followed by Ba. The leaching of Pb only occurred after the second interval and decreased slowly in the subsequent intervals. This showed that the Polymal and Hetron resins were able to retain the heavy metals more effectively in the solidified specimens.

Cumulative Fraction Leached (CFL)

The linear relationship between cumulative fraction leached and square root of leaching time in all cement-based and polymeric resin treated samples indicated that diffusional process is the main transport phenomenon for the leaching of the heavy metals.

In cement-based treated samples, Ba contributed the highest CFL among the heavy metals of concern and it declined as the cement loading decreased. On the other hand, the CFL of other heavy metals increased as the dust loading increased. The CFL of Ba and Zn has reduced by more than 50% after addition of activated carbon. CFL of other heavy metals declined as well, but less pronounced.

The leaching trend for the three heavy metals detected (Zn, Ba and Pb) were consistent for all the resin:dust ratios. Zn contributed the highest CFL, followed by Ba and Pb, but in descending trend as the dust loading increased. The CFL of the heavy metals detected in all Hetron treated samples were comparatively higher.

Leachability Index (L_i)

All the Leachability indices exceeded the guidance value of leachability index of 6 and ranged from 7.6 - 10.0, clearly indicating that the heavy metals were well retained in the solidified specimens. Despite small differences in L_i values for all the heavy metals, there is a correlation that the L_i decreased as the waste loading increased.

While higher L_i was obtained for cement with activated carbon treated samples as compared to cement treated samples, the L_i for both polymeric resins were much higher. This indicates better retention capability of the heavy metals by the resins. However retention capability declined as the waste loading increased.

In addition, it is noteworthy that the amount of MEK initiator added did not contribute to the leachability of the heavy metals of concern.

5.3.3 Physical Characteristics

Hardening Time

Generally, the cement-based binder took longer time to harden (30 - 96 hours), whereas hardening time was significantly reduced to 1.5 - 12 hours for polymeric resin solidification with the addition of MEK initiator. As expected, the higher percentage of initiator (5%) shortened the hardening time as compared to 3% initiator.

Compressive Strength

The compressive strength of the cement-based solidified samples were in the range of 1 - 12 MPa. The compressive strength of solidified specimens increased as the cement loading increased and also as the days progressed. However the compressive strength reading for both cement and cement with activated carbon treated samples were far below that of the control, which were in the range of 41.77 - 57.55 MPa and 41.93 - 57.62 MPa respectively, as the days progressed to 28 days.

As for the polymeric resins, the compressive strength readings were much higher (53 - 68 MPa) and relatively consistent as the days progressed over 28 days. Relatively higher compressive strength was obtained in Hetron treated samples, including the control, as compared to Polymal treated samples. The higher percentage of MEK initiator added to the resins did not seem to cause any significant effect on the ca of the solidified samples.

5.4 CONCLUSION

Cement-based solidification was able to reduce the leachability of the heavy metals of concern. With the addition of activated carbon, it has further reduced the leachability of the heavy metals. The polymeric encapsulation was superior than the cement-based solidification. Among the two polymeric resins, Polymal showed better performance on heavy metals retention capability, whereas Hetron exhibits higher compressive strength.

However, in terms of cost effectiveness, both the cement-based solidification and polymeric encapsulation increased the waste volume as well as weight and hence increased the cost of transportation and disposal.

Recycling of brake lining dust seems to be the most feasible and preferable option as it can reduce the amount of waste to be disposed and simultaneously able to increase the amount of income. However, further research need to be carried out to explore the feasibility to recycle the brake lining dust.

5.5 SUGGESTIONS

1. Good housekeeping and regular maintenance should be of primary concern in waste minimization because some trivial steps can contribute considerably to the reduction of the waste generated.

2. Modify all the current brake lining molds to the required dimensions in order to reduce the needs for cutting, grinding and chamfering. Consider using cement molds instead of steel molds because it is cheaper and presents a comparable strength as the steel mold.

3. Recycle the brake lining dust by mixing with the virgin mix to produce comparable quality brake lining.

4. Restraining the packaging waste, such as carton, plastic sheets, by changing the method of packing. Use corrugated cardboard box with a flap, so that it can be sealed without tape and easily folded inside. Design the box so that it can be used repeatedly for many times.

5. Use returnable boxes or plastic containers for goods-delivery in order to reduce packaging.

6. Establish complete waste-segregation and separate collection system to ensure homogenity of the waste generated and to facilitate recycling or material recovery.

7. Reduce the operation time by increasing working speed in the production line in order to reduce the overhead.