Greening Cement-Based Products with Waste Powder Paint (WPP)

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Problem Statement and Significance

- Powder paint is used in many industries including automotive and furniture manufacturing industries. **During its application, a significant amount is wasted.** The **waste powder paint (WPP) amounts to 1.5 million pounds per year from 6 companies alone, in Michigan** (GMI 2012).
- **Recycling process of WPP is challenging** because of the degradation of re-processed polymer in powder paint and the high volume of waste exceeding the capacity of outlets. Thus, **restricting to dispose the WPP in landfills**.
- Industry byproducts have been used in cement-based products for improving the properties of the latter. Therefore, there is a **possibility of using WPP in cement-based products**, without processing.
- **Investigation** is necessary for the **WPP usage in cement-based products**.

Objective and Scope

- The overall objective of the research project is to investigate the influence/interaction of WPP, cement, supplementary cementitious materials (SCM), and chemical admixtures on the fresh, hardened, and durability properties of the cement-based products. Also, to standardize WPP application, reduce WPP getting into landfills, and conserve cement usage.

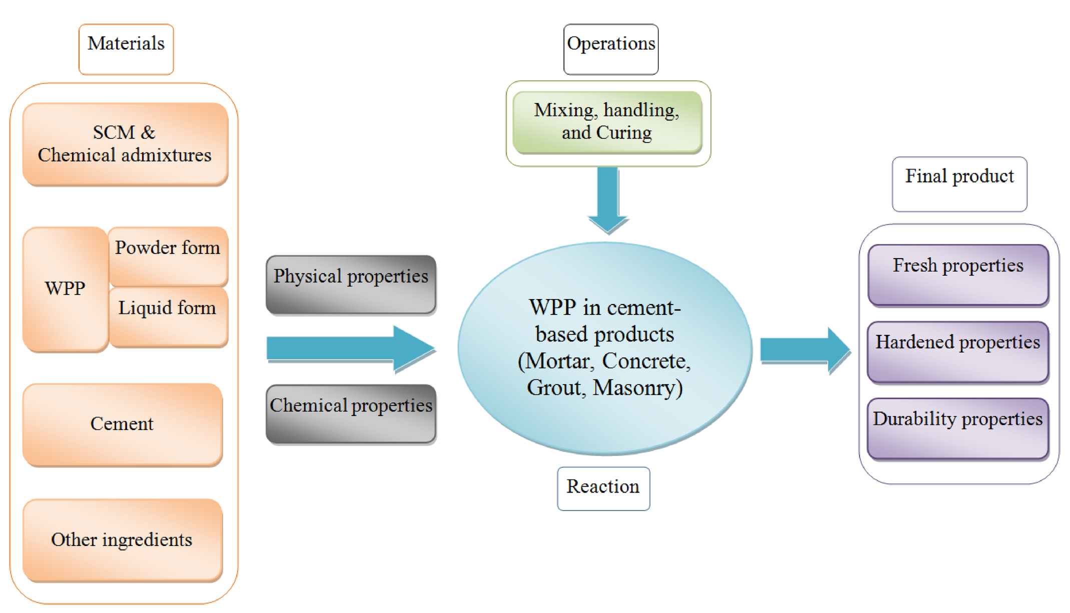

Figure 1. Graphical representation of the research objective

- The scope of the preliminary studies is limited to **evaluating fresh and hardened properties of cement-based products, such as grout, with WPP**.

Methodology

Evaluating chemical and physical properties → Small scale testing of grout with WPP → Results interpretation to identify the properties that are altered with WPP → Large scale testing of cement-based products with WPP → Develop standards for the WPP application in cement-based products, promoting sustainability

Chemical and Physical Properties

- The **WPP is made of different types of polymers** (Figure 2) and has characteristics analogous to cement admixtures. **The cement-based industry has a proven track record of using** fibers, **polymers** and polymer-modified particles **to improve concrete, grout, mortar, and masonry properties.**

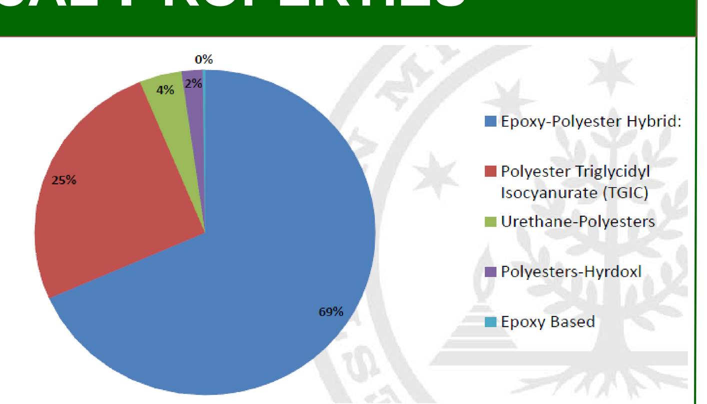

Figure 2. Composition of WPP (GMI 2012)

- About **95% of cement particles are smaller than 45 µm** (PCA 2003). Hence, **WPP size** (Figure 3) **is comparable to cement.**

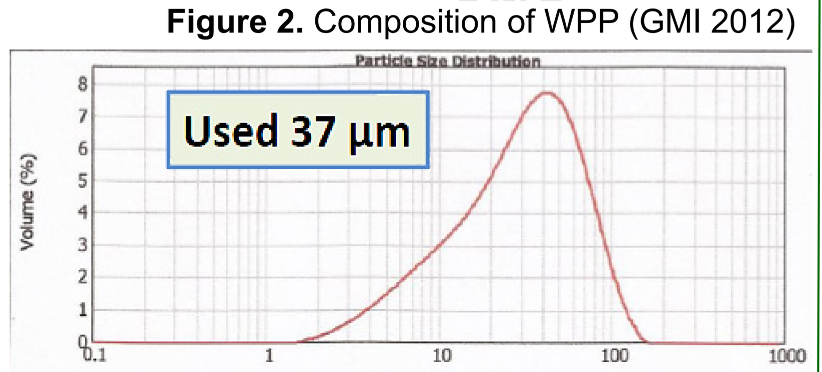

Figure 3. Particle size distribution of WPP (GMI 2012)

- **WPP has three different transition temperature ranges** (shown below) (Graewe and Rettig 2002). Hence, there is a possibility of phase-transition of WPP in cement, because **cement hydration temperature may reach 60°C – 70°C.**
  - Glass transition temperature of WPP → 30°C – 60°C
  - Rubber-elastic state temperature of WPP → 50°C – 100°C
  - Melting temperature of WPP → 90°C – 190°C

Heat of Hydration Test

- Comparing the test results (Figure 4) with the typical curve (Figure 5), a **dormancy period** of around **2.5 hrs** was observed for all the mixes.
- **Reduction of about 22.4% and 29.1%** in the maximum hydration temperature **for the 10% and 20%** WPP mixes was observed, compared to 0% WPP mix.

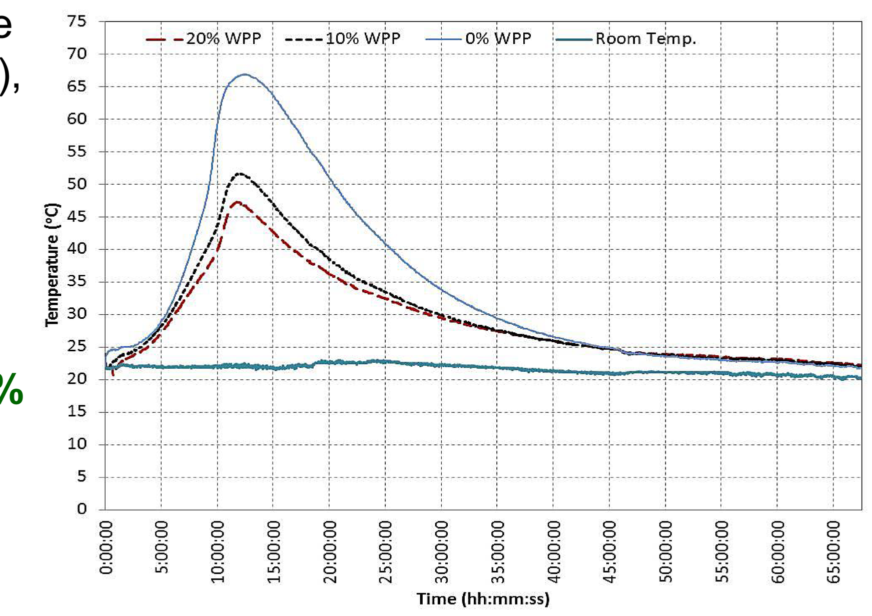

Figure 4. Heat of hydration in specimens with WPP

Table 1. Test Details

ASTM Standards	ASTM E220, ASTM C1074, & ASTM C186		
W/C ratio	0.45		
Type-I cement (g)	600		
Water (ml)	270		
WPP as a cement replacement (%)	0	10	20
Mixing-water temperature (°C)	20.8	17.5	16.2
Weight of the test specimen (g)	750	750	750

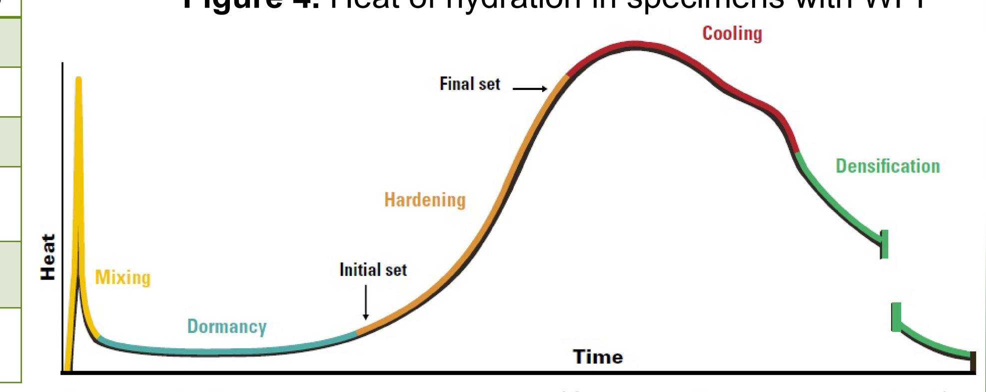

Figure 5. Typical hydration curve (Source: Taylor et al. 2006)

Compressive Strength Test – w/o Curing

- The test was performed on the specimens that were kept in **adiabatic conditions, without external curing, for up to 7 days.**
- It can be inferred that the **strength developed** during the hardening process of the mixture, **without external curing, is not affected by addition of WPP,** although there was reduction in heat of hydration (Figure 4).

Table 2. Test Details

ASTM Standards	ASTM C39 & ASTM C109		
W/C ratio	0.45		
Type-I cement (g)	600		
Water (ml)	270		
WPP as a cement replacement (%)	0	10	20
Mixing-water temperature (°C)	20.8	17.5	16.2
Weight of the test specimen (g)	749.5	717.5	715
Diameter of test specimen (cm)	7.07	7.19	7.13
Height of test specimen (cm)	7.86	8.07	8.09
Volume of test specimen (cm3)	308.72	327.63	323.96

Table 3. Compressive Strength Results

Specimen	C/S area (Cm^2)	Maximum load (kN)	Compressive strength (Mpa)
0% WPP	39.27	10.74	2.74
10% WPP	40.61	9.45	2.33
20% WPP	40.00	10.15	2.54

- **Compressive strength** values were found to be **equivalent** for the specimens (Table 3), without external curing.

Compressive Strength Test – w/ Curing

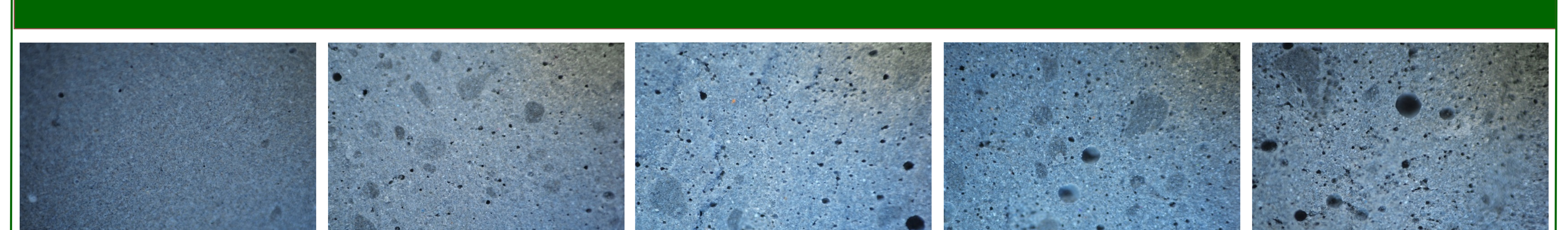

Figure 6. Texture of the grout specimens with respective WPP contents

- Continuous curing was provided until the **test age (3, 7, and 14 days).**
- In general, **an increase in WPP content in the grout, lowers the early age strength** (up to 7 days).
- With **continuous presence of moisture,** the **strength in WPP specimens increases.**
- 7.5% WPP specimens show different behavior that requires additional investigation.

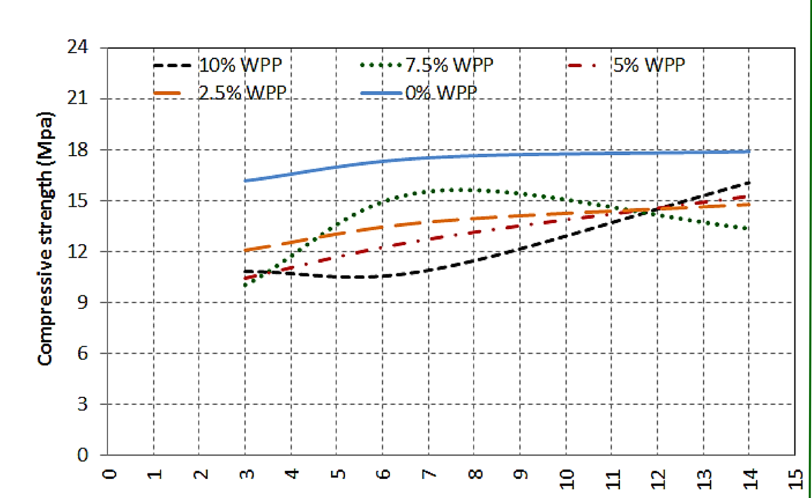

Figure 7. Compressive strength curves w/ curing

$$\text{Increase in Strength}\,(\%) = \frac{\text{Strength}_{(7\text{ day or }14\text{ day})} - \text{Strength}_{(3\text{ day})}}{\text{Strength}_{(3\text{ day})}} \times 100 \quad \rightarrow (1)$$

- The possible reasons for the decrease in compressive strength could be as follows,
  - Reduction in cement content.
  - Abundant air-voids in specimens with WPP.
  - WPP may have affected the crystalline formation of cement matrix, without contributing to strength.

Table 4. Results Summary

Specimen	Percentage increase in strength (Eq. 1)	
	At 7 days	At 14 days
0% WPP	8.37	10.63
2.5% WPP	13.70	22.29
5% WPP	22.00	46.20
7.5% WPP	67.65	44.02
10% WPP	2.64	51.19

Early Age Shrinkage/Expansion Test

- Generally, **the cement grout is expected to shrink** at the early age. But during the casting of the **cement grout specimens with WPP, an unusual phenomenon of cement grout expansion was observed** (Figures 8 & 9).

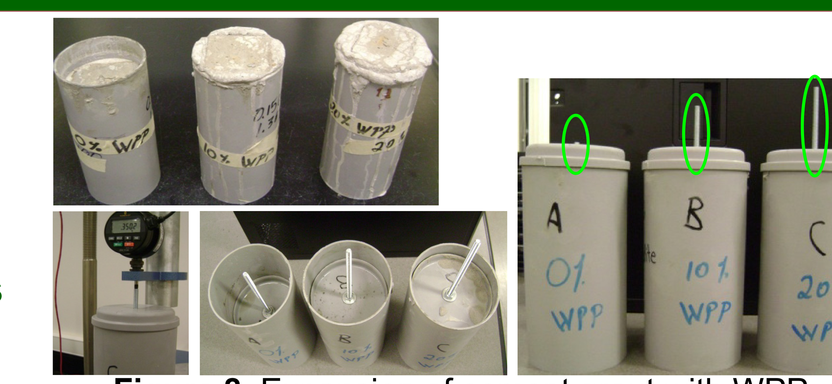
Figure 8. Expansion of cement grout with WPP

- **Equal weights of cement grout** mixture were used to cast the WPP specimens. The **0% WPP specimen started shrinking after starting the test**, whereas, the **specimens with 10% and 20% WPP started expanding after 10 to 15 min delay** (Figure 9). The **expansion** of WPP specimens **ceased after 2.5 hrs**. Considering the heat of hydration curves (Figures 4 & 5), it can be inferred, **expansion occurred before initial setting.**

Table 5. Test Details

ASTM Standard	ASTM C827		
W/C ratio	0.45		
Type-I cement (g)	1500		
Water (ml)	675		
WPP as a cement replacement (%)	0	10	20
Mixing-water temperature (°C)	21.2	19.0	19.2
Weight (g)	1700	1700	1700
Diameter (cm)	10.16	10.16	10.16
Initial height (cm)	11.40	12.30	12.70
Final height (cm)	11.12	14.90	17.27

Table 6. Results Summary

Weight % of WPP	Effective expansion (%)
0%	-2.45
10%	21.13
20%	35.98

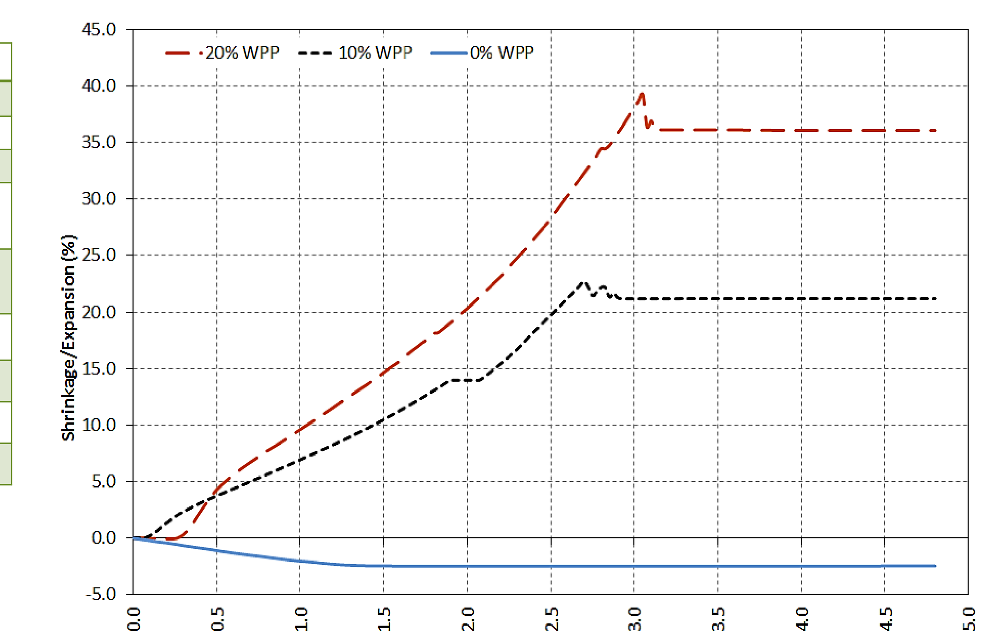

Figure 9. Percentage change in height of WPP mix specimens

Absorption Test

- Cylindrical specimens (Figure 8) were prepared allowing 1-D free shrinkage/expansion and were cut into two portions (Figure 10) to be used for this test.


Figure 10. Prepared specimens

Table 7. Test Details

ASTM Standard	ASTM C67		
W/C ratio	0.45		
Type-I cement (g)	1250		
Water (ml)	562.5		
Drying temperature (°C)	Trial-1	Trial-2	Trial-3
	65.5	65.5	115.0
WPP as cement replacement (%)	0	10	20
Weight (g)	1100	1100	1100

Table 8. Details of the Specimens

Label	Height (cm)	Diameter (cm)	Volume (cm^3)
0%-B*	5.62	7.65	257.93
0%-A	5.32	7.64	243.51
10%-A*	6.51	7.70	303.32
10%-B	6.30	7.59	285.13
20%-A*	6.65	7.67	307.42
20%-B	6.88	7.62	313.65

(*) represents top portion of specimen

Table 9. Results Summary

Label	Absorption (%)			Extra (%)
	Trial-1	Trial-2	Trial-3	Avg. diff. w.r.t Trial-3
0%-B*	12.86	13.50	**26.49**	**13.31**
0%-A	10.68	12.00	**24.76**	**13.42**
10%-A*	23.25	23.11	**32.37**	**9.19**
10%-B	14.90	15.77	**26.02**	**10.69**
20%-A*	25.44	24.81	**30.90**	**5.78**
20%-B	16.52	17.09	**24.41**	**7.61**

- The test was performed in 3 trials to identify the effect of drying temperature on absorption.
- **An increase in WPP content**, for trials-1 & -2, **increased the absorption**; however, it **decreased** the **extra absorption** w/ high drying temperature.

Conclusions and Future Research

- **Cement grout with 20% WPP expands immensely,** thus, there is a great potential of using WPP to **develop shrinkage-compensating admixture** for mitigating several issues that are observed due to shrinkage.
- **Porosity of the cement grout specimen with WPP can be improved by heating it up** to a temperature that is in the *melting temperature* range of WPP.
- Less dense specimens were certainly a factor for reduced strength. Thus, **evaluating impact of confining pressure on strength development is vital.**
- **Impact of adding aggregates** and the **chemical reactions**, in **cement & WPP mixture** in liquid form need to be understood from **future research**.
- The outcome of the research could allow **WPP to be used in several civil engineering applications**, such as grouting precast connections & underpinning.

Acknowledgement & Disclaimer

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