Detecting Deleterious Fine Particles in Concrete Aggregates And Defining Their Impact

Proposal to the Wisconsin Highway Research Program

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Problem Statement

Currently, WisDOT specifications limit the fine particle content (passing the #200 sieve) of coarse aggregates to 1.5 percent by weight. There is increasing evidence that within some reasonable limits this is not an issue of the *quantity* of fine material but rather its mineralogical nature. Clays have been shown to influence the parameters controlling hydration of the cement paste and providing a structural barrier to the bond with aggregates.

During the past year, this problem has been further researched and WisDOT has been conducting the California Cleanness Test (CCT) as part of a monitoring process for aggregates. Further problems have occurred in the field with some evidence, and the judgment of the technical personnel involved, that aggregate coatings have been a contributor to these troubles. Research has shown that certain types of clay particles can be very adverse to concrete through their absorption of water resulting in problems with the aggregate-paste interface and possibly interfering with the hydration of the paste (Gullerud and Cramer 2002, Munoz et al. 2005). Other clays are innocuous. Unfortunately, the CCT is not sufficiently discerning with respect to its ability to identify these problematic clays. In addition, experience at WisDOT has suggested that the ½ hour time required to conduct the CCT per sample may be too long under the manpower constraints existing currently in the WisDOT. This problem is exacerbated by the fact the CCT does not provide exactly the information required even if it is an improvement over the current 1.5% fine particle limit.

Isolating the real influence of aggregate coatings is not simple because the quantities of aggregate coating tend to be small and chemical interactions depend on the mix constituents which vary from paving job to paving job. Typical standard test procedures may not always be able to identify the clay-associated mechanisms at work in the concrete mix.

Previous research on fine particles and the harmful impact of clays has focused on coarse aggregate coatings. Since most coarse aggregates in Wisconsin are washed, the amount of coating is relatively small but not necessarily harmless. In addition, to coarse aggregate coatings, clay particles can also be introduced as a minor fraction in fine aggregate. In this situation the fine aggregate particles may overwhelm any influence of clay coatings on coarse aggregates. In other situations, the fine aggregate portion may add to or interact with coarse aggregate coatings to exceed innocuous thresholds.

Research Objectives

The objectives of the research are to:

1) Develop a rapid test to detect clay particles in aggregate sources that is both indicative of their quantity and their physical and chemical nature. This is intended to indicate whether these clays are harmful or innocuous.
2) Quantify the impact of total (from combined coarse and fine aggregates) clay content on concrete strength development, shrinkage and porosity. Advance a fundamental knowledge of the role of clays in concrete performance so that mitigation strategies can be formed in future research.
3) Quantify clay content from several Wisconsin sources of aggregates to determine the relative contribution of clay fines from coarse aggregates and from fine aggregates.

Background and Significance of Work

Current Wisconsin Department of Transportation (WisDOT) specifications (WisDOT 2005) limit the amount of fine materials in coarse aggregates used for concrete fabrication to 1.5% by mass of the total coarse aggregate and 3.5% by mass for fine aggregates. Fine materials are defined as those passing the No. 200 sieve (p200). In recent (WisDOT) paving projects, there has been a growing perception that the cleanliness of coarse aggregates can significantly influence the performance of concrete produced using portland cement. Of specific concern are the silt and clay-sized particles that remain after washing that adhere to the surface of some igneous gravels. While such a perception exists, prior to the WHRP study we recently completed (Gullerud and Cramer 2002), there was not hard evidence that quantified the influence of aggregate coatings on concrete strength or durability. It was unknown whether current efforts of aggregate producers in washing aggregates to remove these fine particles were sufficient or insufficient to ensure good performance of these materials. For now it appears washing is well advised and further washing is unwarranted.

While coarse aggregate is washed and the quantity of fine materials is limited, fine aggregate often from the same geological and geographic source can also introduce quantities of the same type of clay. The appearance of a clay coating on coarse aggregate may be a visual clue that clays coating are present in the subject geological source and thus may also be entering the concrete mix in the fine aggregate. While small levels of coarse aggregate coatings may be tolerable, the true level of clay fines introduced via a given geological source may well be higher. Our previous research has shown that aggregates with clay coatings and a p200 percentage near 1.5% of the mass of the coarse aggregate can potentially produce noticeable changes in slump and durability. Drying shrinkage increased by approximately 65% when extensive clay coatings were present. Impacts on workability were significant and could prompt field additions of water that may negatively impact other concrete properties

But not all clays behave the same in concrete. The use of clays as pozzolan additives in concrete was widely studied in the past and the effects of some of them on certain concrete properties are well known. It was reported that the replacement of different amounts of cement, or in other cases sand, by natural clays produced changes in the strength and in shrinkage (Changling et al 1995, Moukwa et al 1993, Pike 1992, and Unikowski 1982). All of these studies were performed by using significant amounts of clays as additives. In real situations, clays could be present as a part of fine aggregates and as natural coatings on coarse aggregates and consequently could be present in concrete in smaller but still significant amounts affecting the final quality of the concrete. During the mixing process a fraction of the clay in coarse aggregate coatings could be released into the aqueous phase while the rest will remain attached to the surface of the aggregate. In recent study with clay coated aggregate (Munoz et al 2005), we discovered that the amount of clay detachment depends on the nature of the clay: Na-montmorillonite mostly remains on the aggregate upon mixing (10 and 20% detached, at pH~7, and 12 respectively), Ca-montmorillonite and kaolin detached very readily and entered the water phase (Ca Montmorillonite: 69 and 77% and Kaolin: 50 and 79 % for pH~7, and 12, respectively) [Munoz et al 2005]. Therefore, it is likely that clays may modify two zones in the concrete structure. One these zones is the cement paste itself and the second is the interfacial transition zone (ITZ). Based on preliminary results, it is our perception that the effect of clays will depend upon the type of clay and which zone it affects.

The effects of some type of clay in cement pastes were explored in our recent work. Results revealed that cement paste having Ca-montmorillonite and Kaolin as opposed to control sample (no clay present) accelerated the rates of hydration reactions. On the contrary, when cement paste contained Na-montmorillonite, the hydration reactions were retarded including the formation of ettringite. This effect of retardation could be explained by the ability of Na-montmorillonite to absorb water (Changling et al. 1995) and, in some cases, creating isomorphic gels or semipermeable membranes around hydrating cement particles (Fam and Santamarina 1996). Therefore, less water is "available" to hydrate cement compounds or even the formation of these semipermeable membranes tend to enclose particles of cement during their hydration. Finally, Ca-montmorillonite and Kaolin clays that show low absorption of water, act as pozzolans and tend to accelerate hydration reactions.

Until now, we have been discussing the potential effects of clays coming from the fraction that has detached from the aggregate in the bulk of the cement paste of a concrete mixture. However, as mentioned above, there is a fraction of clay coating remaining on the coarse aggregate particle in fresh concrete. This fraction is likely to have a more profound influence on the physical chemical properties of the mortar forming the interfacial transition zone (ITZ) of the concrete. In this interfacial region, the concentration of clay particles is much larger than that in the bulk cement of the concrete. In addition, the presence of a layer of clay particles coating the aggregate is expected to decrease the interlocking shear strength between the cement paste and the aggregate. The layer of unreacted clays in hardened concrete may influence the durability of concrete. It could have a large potential for interacting with deicers and may develop an alkali silica type reaction (ASR). The development of ASR across the clay coatings is expected to be magnified and occur faster as compared to that on the surface of normal aggregates. Clay located in ITZ could act as a reservoir of suitable material for developing of ASR with time.

We already discussed two of the factors (detachment of clays and absorption of water) that will govern the behavior of the clay in concrete. Another factor that should also be considered to predict the effect of clays on concrete is the particle size of the clay. This factor could have an important influence in durability properties of the concrete. For example, the formation of alkali silica gels has been connected not only with the reactivity of the fine aggregates but also with size of these particles. The expansion provoked by the ASR increase with a decrease in the size of the reactive particles in the range of 15 – 0.15 mm (Zollinger et al. 2001). In our case, clays in microfine coatings usually are present in a smaller range of size, between 0.1 mm and 1 μm. For this range of size, the ASR expansion should decrease as the size of clay turn smaller. As clay become smaller and smaller, more specific surface area is available to easily react with cement reactants and disappears rather than stay unreactive. While Wisconsin is generally considered to not have ASR susceptible aggregates, this does not mean that ASR malfeasance does not occur in hydration process of problem concretes that have clay fines. As in the case of clays located in the ITZ, unreactive clays present in the cement paste after the initial hydration of cement, could act as reservoir of suitable material for ASR developing.

Therefore, according to the literature as well from our previous results, we believe that the harmful and helpful aspects of clays in concrete performance could be assessed by monitoring three characteristics of these clays; 1) The ability of the clay to detach from the aggregate surface, 2) the capacity of the clay to absorb water - this could be related with the specific surface of the clay

(Changling et al 1995) and 3) the particle size of the clay. Different combinations of these three factors could be used to establish the grade of deleterious versus positive effects of the clay coating as represented in Figure 1.

In this ternary diagram we can distinguish four types of clays:

I) Beneficial Clays. These clays will be characterized in the diagram for clays that easily detach from the aggregate surface, and have low specific surface and smaller particle size. These clays of smaller size will be mostly dispersed in the cement paste. Therefore, it is expected that these clays will react in the initial hydration process with the early hydrated products, mostly $Ca(OH)_2$, to produce calcium silica hydrated (CSH). This means that the clay will act as a typical pozzolanic additive (Sabir and Wild 2001). The increase of CSH in concrete will likely have some beneficial effects, such as improved compression strength, decreased average pore size, especially in mortars, and increased resistance to the development of ASR (Sabir and Wild 2001). Another characteristic of these clays will be their low specific surface and therefore their poor tendency to absorb mixing water.

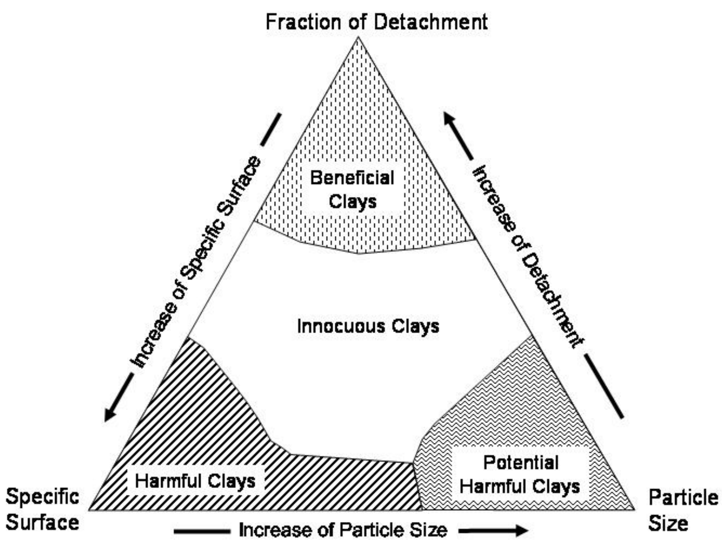


Figure 1. Hypothetical Diagram to Predict the Effect of Clays in Concrete

II) Potentially Harmful Clays. The clays that belong to this group will be characterized by small detachment capacity from the aggregate surface, small specific surface and high particles size. In theory, we expect to find an important concentration of larger clay particles in the ITZ. This fact could be detrimental for concrete because this situation could be beneficial for the development of ASR in the ITZ. Therefore, this concrete would be expected to have a tendency of developing, under the right conditions, the ASR.

III) Harmful Clays. This group will be defined by clays which show low ability to detach from aggregate, high specific surface and small particle size. These clays will tend to absorb mixing water and retard the appearance of hydration products. These clays will be mostly concentrated in the ITZ due their low ability to detach from the aggregate.

Even though these clays have smaller particle size they will be coating the aggregate surface and this coating configuration could decrease the strength between the aggregates and the bulk, and might also be suitable for developing the ASR.

IV) Innocuous Clays. The presence of these types of clays should not alter the normal quality parameters of the concrete. These clays will be characterized by a moderate capacity of detachment, medium specific surface and particle size.

The ternary diagram presented sets a hypothesis for this project and the exact limits of the four proposed areas are not well known. The work presented in this proposal is oriented to corroborate if the parameter of clays selected, such as fraction of detachment, specific surface and particle size, are able to predict harmful effects in the quality of the concrete, mostly in the strength and durability developments. And also, by selecting real samples, we expect to be able of define more accurately the limits of these four groups. By defining these limits we lead to a proposed new testing method for clays.

Benefits of This Study

Aggregate coatings and fine particles in aggregates continue to be anecdotally identified as the source of strength development, cracking and construction problems in concrete paving. In addition, it now appears they may also be linked to concrete durability. A test that distinguishes harmful particles from innocuous particles is needed and will provide a basis for managing the problem in practice. Better definition of the distinguishing characteristics of harmful particles and their impact on concrete performance would facilitate an economical supply of concrete aggregates that would reliably provide a consistently strong and durable concrete product. Understanding the impact of clay particles on concrete performance is the first step in developing methods to mitigate these impacts. Research proposed in this study will identify the amount and nature of clay particles from combined coarse and fine aggregate sources in the State. It is possible that when considering the total aggregate source (fine and coarse aggregates together), that clay contents may be higher than previously thought.

Implementation

The test to be developed under the proposed research will likely be adopted and implemented by WisDOT, the aggregate industry and researchers as a screening tool. It is expected that WisDOT would build its aggregate acceptance specifications for concrete construction around this test or some version thereof. Research examining the clay content of combined coarse and fine aggregates will lead to new specifications which better define acceptable and unacceptable aggregates. The test and anticipated outcomes of this research are expected to have national significance.

Detailed Work Plan

Test Method to Detect and Classify Clay Particles

A test method will be developed to replace or supplement the current p200 fine material limits for coarse aggregates in concrete and to remove the undesirable limitations of the California Cleanness Test (CCT). The p200 test does not and cannot distinguish between harmful and acceptable coatings. The alternative methods are more accurate than p200 in terms of detecting harmful coatings but also present some significant disadvantages. For example, the CCT shows a major capacity to detect the presence of harmful coatings but cannot differentiate between small particles with long sedimentation times and clay particles with macroscopic swelling. Another alternative, the methylene blue test, seems to be a more precise method to detect and semi-quantify the presence of undesirable coatings and it may correlate to the shrinkage of the concrete. The main disadvantage is that in its current form, the final results depend on operator subjectivity. While there have been unpublished efforts[1] to modify this test to render it less subjective, other disadvantages remain. The test operation with methylene blue can be messy and cumbersome. With these issues in mind, the new method should:

- ☐ show a similar or improved ability compared to the methylene blue test for detecting clays while suppressing all subjectivity,
- ☐ not require expensive equipment,
- ☐ be conducted in a short amount of time (CCT and methylene blue test, require at least 30 minutes to complete),
- ☐ not require unreasonable training or knowledge.

Based on the above criteria and considering the three characteristic of clays that define the harmfulness on concrete (detachment of clays, absorption of water and particle size), the research group decided that a focus on the Cation Exchange Capacity (CEC) of clays is the most promising parameter by which to screen fine materials in aggregates.

Clay could be defined as combination of two planar or sheet structures, one made of tetrahedrons formed by one Si^{4+} link to four oxygen atoms and the second one formed by octahedrons. The main atom in the octahedron could be Al^{3+}or Fe^{3+} with hydroxyl and oxygen atoms as ligands. The main atoms in both tetrahedral and octahedral sheet structure could suffer isomorphous substitutions. That means that they can be replaced by atoms with similar size but different charge, such as Si^{4+} could be replaced by Al^{3+} or Fe^{3+}. The cations in the octahedral structure can be substituted by Mg^{2+} and Mn^{2+}, respectively. As a consequence of these substitutions with minor valence atoms, the sheet structures show negative "sites" along the surface. This development of negative charge is compensated with the presence of external cations. These cations are attracted with different intensities to the sheet structure and depend on the nature of the clay. When clays are immersed in aqueous solutions, these external cations can be exchanged with the electrolyte contained in the aqueous solutions. This phenomenon is defined as CEC (Chiappone et al 2004) and it will be different depending on the nature of the clay (Table 1). The CEC of the clays could be related with other clay properties such as absorption of water. It has been demonstrated that clays with high specific surface area, and therefore high ability to absorb water, show high CEC (Nalbantoglu 2004). It should be noted that CEC could be related not only with the specific surface of the clays but also with its negative charge present in the clay sheet structure, due to the isomorphous substitutions (Chiappone et al 2004). Clays characterized by high specific surface and high negative charge usually present high CEC.

[1] Personal communication with Vulcan Materials - 2005

Table 1. Typical exchange capacity of most common minerals.

Type of Mineral	**CEC (meq/100g)**
Smectite	80-150
Mixed-layer (Illite/smectite)	10-150
Illite	10-40
Kaolinite	2-13
Chlorite	10-40
Vermiculites	100-150

Reference: Grim (1953)

Based on the values present in Table 1, we can hypothesize which clays will be undesirable depending on the measured value of CEC.

1. Harmful Clays: Clays that will present high values of **CEC > 100 meq/100g** such us Smectites and Vermiculites will likely be harmful. These clays will present a high capacity for absorbing water and high negative charge in the clay sheet. This high negative charge could be related to its ability to attach on the surface of the aggregate, so these clays will be concentrated on the surface of the aggregate after the mixing process.
2. Potentially Harmful Clays: The range of **CEC** between **40 and 100 meq/100g** will present an intermediate risk to concrete performance. This group will be formed by clays with a less capacity of water absorption than the previous group.
3. Innocuous or Beneficial clays: This group of clays will show **CEC < 40 meq/100g** and will be considered innocuous or even potentially beneficial. These clays will exhibit low water absorption capability and low negative charge. We expect that clays with these small values of CEC will be easily detached from the aggregate surface and get disperse in the cement paste.

The CEC will be assessed by measuring the conductivity of the samples when immersed in different electrolyte suspensions. The conductivity is a unit measure of electrical conduction and could be defined as the facility with which a substance conducts electricity. In aqueous suspension of electrolytes, the conductivity is a result of the motion of the ions under the effect of an electric field. The conductivity in the suspension will depend on several factors, such as temperature and the cation present in solution. The conductivity of the cation will be affected by the "facility" of movements of this cation in water. This "facility" of movement will depend on the total charge and size of the cation; for example larger cations have a higher resistance to motion in water than smaller ones.

The aim of the new detection method will be the determination of the CEC by measuring the conductivity of clays immersed in different electrolyte suspensions. As mentioned before, when clay is immersed in an electrolyte suspension, it will tend to exchange the cation located between sheet structures with the cation present in suspension. This exchange of cation will induce a change in the solution conductivity that will be measure. The value of the conductivity could be related with the concentration of ions present in the solution and therefore with the CEC. All the measurements will be performed with a standard conductivity meter which is a low-cost and common piece of laboratory equipment.

A possible test sequence based on these concepts is itemized below:

1) Remove fine material from coarse or fine aggregate by established washing or sieve procedures.
2) Mix a specified amount of the sample (between 30-120 g) with 500 ml of a selected electrolyte solution.
3) Stir for 5 to 10 minutes.
4) Measure of conductivity with a conductivity bridge (cost approx $100)
5) Calculate values of CEC and content of clay then compare with empirical database established as part of the proposed research.

The research effort will focus on developing, calibrating and verifying the proposed test procedure, establishing which electrolyte solutions are most appropriate, and building a database upon which to judge CEC values for field clays.

Sampling of Wisconsin Coarse and Fine Aggregates

A second phase of this research will examine the clay content of combined coarse and fine aggregate sources in Wisconsin and evaluate concrete samples made with higher levels of clay. The purpose is to provide the field data by which to develop and refine the screening test identified above and to explore the hypothesis that the combined fine and coarse aggregate clay content is more important than considering aggregate coatings of coarse aggregate separately, given that all prior work has focused strictly on the contribution from coarse aggregate coatings alone.

We intend to identify combined coarse and fine aggregate sources from projects in the 2007 to 2008 construction season for screening and possible further study. This project is not large enough to broadly sample and to definitively answer all questions related to this issue. It is expected that those sources selected will be using the same geological source and geographical location to mine aggregates for both the fine and the coarse categories. Samples of fine material will be screened with the new test procedure proposed above. Based on the outcome of the screening test, between one and four aggregates will ultimately be selected for concrete sample preparation and evaluation.

Evaluation of Concrete

Our proposed evaluation plan of concrete containing clay fines is guided by our previous experience (Gullerud and Cramer, 2002). The impact of aggregate coatings has historically been so poorly understood because the quantity of clay is often small and observing a statistically significant impact on standard ASTM-type tests (which themselves are variable) can be extremely difficult. Although, in some cases of well-behaving laboratory concrete the impact of the clay particles from coarse aggregates alone is small, out in the field other situations are presented. Combined aggregates may introduce larger quantities of clay particles, chemical reactions may be impacted by a wide variety of mix constituents including different brands of portland cement, fly ash, other mineralogical forms of dust coatings and more. Therefore to unlock this puzzle, the impact of the clays must be understood at a micro and chemical level and then correlated with macroproperty tests such as strength and shrinkage. We have purposely excluded freeze-thaw durability testing from this proposed research because it is variable, more information on the basic mechanism of clay interaction needs to be first established and because of the limited scope of this project. Instead, we will conduct a series of microstructure tests that will provide a basis for understanding potential impacts on durability and, later in future research, targeted freeze-thaw testing.

From each aggregate selected, two concrete batches will be produced: one with a specified water/cement ratio (such as 0.42) which includes the typical absorption values for aggregate but neglects the extra absorption characteristics of the clay fines. The other will use a water content which accounts for both the normal absorption of the aggregate and the absorption of the clay fines. It is anticipated that the workability of the first mix will be impaired while the second mix will be more workable. The overriding questions will be to what degree do the clay particles imbibe water, and as water is added to the concrete mix to provide sufficient workability, does the additional water impair the concrete porosity, reduce strength and increase the shrinkage of the mix. During the mixing process we expect a portion of the clay particles from the combined coarse and fine aggregates to mix freely in the cement paste and a portion to cling to the coarse aggregate surface. That is why this last task will focus on analyzing the effects of clays on the cement paste and the ITZ. To achieve the objective we will monitor the kinetics of the hydration reactions and the influence of these microfines on the cement paste morphology and specifically whether these microfines present in cement paste or in the ITZ are able to alter the pore structure. Specifically we will undertake the following:

1. Define the distribution of the microfines during the mixing process. This quantification will be done at small scale with a procedure which simulates drum mixing. We will establish how the microfine clay particles distribute in the concrete: what portion forms in the ITZ, what portion disperses in the cement paste matrix.
2. Prepare concrete. Different concrete mixes will be prepared using Type I portland cement, air entrainment, and aggregates previously selected. Tensile and compressive strength cylinders and drying shrinkage prisms will be cast from each batch as appropriate for the test series. Air content will be measured as wellas slump and unit weight.
3. Perform tensile and compressive strength testing at 2 different ages following ASTM C39 and C496.
4. Perform drying shrinkage test according to ASTM C490.
5. Microanalysis of the concrete samples. Several aspects of the samples will be studied using different techniques. The disappearance and appearance of the paste components as a function of time will be followed in order to quantify the impact of the microfines coatings. Also, the microstructure of the samples will be analyzed to correlate durability with microstructural properties of the samples.

    5.1 X-ray diffraction (XRD). The kinetics of the hydration reaction and the ASR will be tracked as a function of time. In the case of the hydration reaction, the disappearance of cement components, such as C_3S and C_2S, will be followed as well as the appearance of hydration products such as calcium hydroxide and ettringite. Special attention will be paid to the development of CSH and the amount of unreactive CH that remain in the sample, since these two aspect are indicators of the pozzolanic effect of the microfines (Sabir and Wild 2001). All the XRD samples will be analyzed with the presence of an internal standard, in our case CaF2, to semi-quantify the amount of the hydration products (Ramachandra and Beaudoin 2001). Daily measurements will be made during the first week. After that, samples will be analyzed weekly during the rest of the first month of hydration, after which only monthly measurements will be performed for up to 4 months.

5.2 SEM/EDS. The tracking of the hydration process with XRD will be complemented with sample observations using the electron microscope. The cement paste morphology will be examined to determine its pore structure, the morphology of the components, and if clays are able to alter the microstructure of the cement paste. Also quantitative image analysis will be performed in our samples to determine the difference in porosity between the ITZ and the cement paste matrix (Werner and Lange 1999). We will also examine air void distribution to determine if clay particles influence the occurrence of air voids around the ITZ.

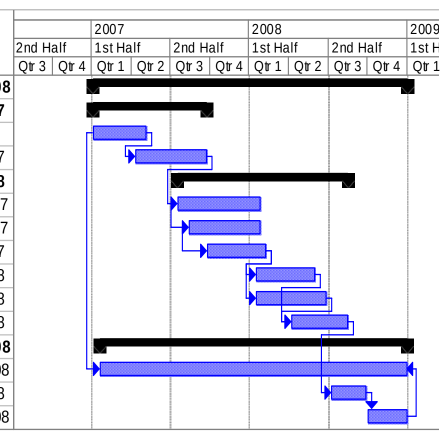
5.3 Measurement of pore size and porosity. We will utilize N_2 sorption and/or Hg porosimetry of the paste samples. The nitrogen sorption measurements may allow us to characterize the nanoporosity of powdered samples of bulk concrete. Pieces of bulk concrete from several regions of the prisms will be combined and powdered to ensure that the sample represents the average property of the bulk concrete. It should be cautioned, however, that this method only measures pore sizes below 100 μm. Pore size and porosity are expected to be indicators of concrete strength and durability.

Work Time Schedule

The proposed work schedule for the project is shown in Table 2. The total project duration is 24 months.

Table 2. Proposed Work Schedule

ID	Task Name	Duration	Start	Finish
1	**Deleterious Fine Particles Total Project by Federal FY**	**522 days**	**Mon 10/2/06**	**Tue 9/30/08**
2	**Task 1: Develop aggregate screening test**	**190 days**	**Mon 10/2/06**	**Fri 6/22/07**
3	Initial clay conductivity tests in different electrolyte solutions	90 days	Mon 10/2/06	Fri 2/2/07
4	Develop, verify, and refine test procedure	120 days	Mon 1/8/07	Fri 6/22/07
5	**Task 2: Demonstrate proposed test and evaluate concrete**	**285 days**	**Mon 4/16/07**	**Fri 5/16/08**
6	Screen Wisconsin combined fine and coarse aggregates for clays	140 days	Mon 4/16/07	Fri 10/26/07
7	Select and obtain aggregates for concrete specimen prep	120 days	Mon 5/14/07	Fri 10/26/07
8	Prepare and cure concrete specimens	100 days	Mon 6/25/07	Fri 11/9/07
9	Evaluate strength and shrinkage	100 days	Mon 10/15/07	Fri 2/29/08
10	Conduct microlevel studies	120 days	Mon 10/15/07	Fri 3/28/08
11	Analyze project data	95 days	Mon 1/7/08	Fri 5/16/08
12	**Task 3: Reporting**	**510 days**	**Wed 10/18/06**	**Tue 9/30/08**
13	Prepare interim reports and TOC meetings as needed/requested	510 days	Wed 10/18/06	Tue 9/30/08
14	Prepare final report	60 days	Mon 4/7/08	Fri 6/27/08
15	Review, revise and submit final report	67 days	Mon 6/30/08	Tue 9/30/08



Reports

Quarterly reports will be provided on research progress. A final report will be provided consistent with WHRP requirements. TOC meetings and other dissemination venues will be pursued as needed and the opportunity arises. National dissemination of the research findings is anticipated.

Qualifications of the Research Team

Professor Cramer has been involved in concrete related research for approximately 15 years. He is a member of the American Concrete Institute and has been a presenter at meetings of the Transportation Research Board and the Wisconsin Concrete Pavement Association. He is the author of over 85 technical papers. His vita is attached (Appendix A).

Prof. Anderson has been active in the area of colloid and interfacial chemistry for more than 30 years. His expertise includes techniques to understand the behavior of surfaces that are subjected to additives such as the admixtures employed in these experiments. He has recently been adding nanoparticles to a variety of materials to better control the physical chemical properties of these materials. Prof. Anderson´s vita is attached (Appendix A).

Dr. Tejedor, is a senior scientist working in the group of Prof. Anderson. She is a solid state analytical chemist with expertise in inorganic chemistry, surface spectroscopy and mineralology. She will be responsible for performing some of the chemistry studies using electrophoretic mobility, nitrogen pore size equipment, and x-ray diffraction. Dr. Tejedor´s vita is attached to this proposal (Appendix A).

Accomplishments of the Research Team

Prof. Cramer has completed over a dozen concrete material research projects in the last 12 years and currently has two projects in progress. From these projects, seven technical publications are in archival journals or conference proceedings and seven WisDOT reports have been completed. The most recent example of his concrete research can be found at http://www.whrp.org/publications.htm. More than a dozen graduate students have focused their graduate education on concrete materials under this program and have proceeded on to employment in industry.

Professor Anderson has over 30 years experience in the area of surface and colloid chemistry and the preparation of nanoporous materials composed of nanoparticulate oxides. He has approximately 160 papers and 25 patents in the science, engineering and application of these materials. Currently, he is investigating the utilization of nanoparticle additions to fly ash admixtures used in high performance concretes.

Dr. Tejedor has 30 years as an expert in surface spectroscopy particularly related to how organic molecules such as surfactants, adsorb to surfaces. She is also been doing research in the area of how water adsorbs to surfaces and how it is released as a function of porosity and pore size. This will be a part of this study.

Facilities Available

The University of Wisconsin Structures and Materials Testing Laboratory includes a concrete materials facility that is equipped to conduct routine (ASTM, AASHTO) and research-oriented concrete specimen preparation and evaluation. The research team has experience from previous WisDOT concrete research projects. This laboratory regularly stocks both limestone coarse aggregates representative of those found in Southern Wisconsin and igneous aggregates representative of those found in Northern Wisconsin. In addition to common concrete mixing facilities, the Laboratory includes a wet room, a temperature and humidity controlled environmental chamber, two freeze-thaw machines, a sonometer for measuring elastic properties, a variety of test machines to measure compression and tensile strength, a walk-in oven and stereomicroscope capable of magnifications to 400x. X-ray diffraction units, scanning electron microscopes and other general purpose scientific equipment are available within the College of Engineering. The laboratory retains the California Cleanness test apparatus and themethylene blue test apparatus from previous research.

The UW Environmental Chemistry and Technology Program at the University of Wisconsin – Madison has the laboratory infrastructure and equipment necessary to conduct the proposed research. Available equipment includes:

Hewlett-Packard Model 5890 Series II gas chromatograph equipped with a Porapak R column and flame ionization and thermal conductivity detectors;

Hewlett-Packard GCD gas chromatograph equipped with electron ionization detector and interfaced with a controlled temperature furnace and a gas phase reactor system;

Shimadzu Model GC-2010 gas chromatograph with flame ionization and thermal conductivity detectors;

Nicolet Magna 750 and Nexus 670 FTIRs with accessories for diffuse reflectance studies of solid-gas interfaces, attenuated total reflectance studies of solid-liquid interfaces, and a gas phase reactor system;

Brookhaven Instruments B2100 correlator for both dynamic and static light scattering studies associated with particle sizing and stability;

Spin coating and dip coating devices for membrane fabrication;

Rheology instrumentation for measuring sol viscosities;

Temperature programmed furnaces for sintering;

Automated gas sorption manifold for BET surface area and pore size distribution determinations;

Micromeritics ASAP 2010 micropore analyzer with chemisorption accessory for determining specific surface areas and pore size distributions in microporous solids as well as adsorption densities of selected gases in porous solids;

Netzsch Model STA 409 / 3 / 410 thermogravimetric and differential thermal analysis equipment for studying phase changes and weight loss or gain during the sintering process;

Digital Instruments Nanoscope III atomic force microscope for studies of surface smoothness and porosities of deposited and fired thin films;

Malvern Zetasizer 3000 for determining particle sizes and mobilities in dilute suspensions;

Gaertner variable angle ellipsometer for determining porosities and thickness of deposited and fired thin films;

Headway electronic spinner for spin coating flat plates;

EG&G Instruments Model 6310 Electrochemical Impedance Analyzer for characterizing impedance properties of thin films;

Solartron SI 1260 Impedance/Gain-Phase Analyzer and SI 1287 Electrochemical Interface for characterizing impedance properties of thin films;

IBM EC/225 voltammetric analyzer;
Denton Vacuum Desk II sputter coating system;
Olympus BX40 microscope with digital camera;
Shimadzu TOC-5000 total organic carbon analyzer;
Perkin Elmer Optima 4300 DV ICP optical emission spectrometer;
Waters HPLC instrumentation (2 units);
Dionex DX600 ion chromatograph with electrochemical detector;
Hewlett-Packard Model 8452A UV-Visible Spectrometer;
Oriel 1000 Watt light source, optical table and coupling lenses;
Several computers for data analysis and report preparation.

Bibliography

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Appendix A

Vitae of Principal Investigators

CURRICULUM VITAE

STEVEN M. CRAMER
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FORMAL EDUCATION:

Ph.D.	Civil Engineering (Structures - Solid Mechanics), 1984, Colorado State University
M.S.	Civil Engineering (Structures - Solid Mechanics), 1981, Colorado State University
B.S.	Civil and Environmental Engineering (Structures) (with honors), 1979, University of Wisconsin-Madison

POSITIONS HELD:

1996-present	Professor, Department of Civil and Environmental Engineering, University of Wisconsin-Madison
1996-1997	Visiting Scientist, Materials Technology Division, Corporate Research and Development, Weyerhaeuser Company, Tacoma, Washington
1990-present	Director, Wisconsin Laboratory for Structures and Materials Testing, College of Engineering, University of Wisconsin-Madison
1990 - 1996	Associate Professor, Department of Civil and Environmental Engineering, University of Wisconsin-Madison
1984 - 1990	Assistant Professor, Department of Civil and Environmental Engineering, University of Wisconsin-Madison
1982 - 1984	Research Assistant, Department of Civil Engineering Colorado State University
1981 - 1982	Instructor, Department of Civil Engineering Colorado State University

GENERAL RESEARCH INTERESTS AND EXPERIENCE:

- Structural Materials - Testing, Modeling, and Mechanical Behavior
- Lumber Strength and Grading
- Analysis and Design of Metal-Plate Connected Wood Trusses
- Structural Performance of Wood Assemblies
- Fire Performance of Structures
- Concrete Materials Performance and Durability

SCHOLARLY HONORS, TEACHING AND RESEARCH AWARDS:

- Chi Epsilon - Member (Civil Engineering Honor Society)
- Phi Kappa Phi - Member (Physical Science Honor Society)
- Tau Beta Pi - Member (Engineering Honor Society)
- U.W. Polygon Engineering Council Outstanding Civil and Environmental Engineering Faculty Instructor, 1987, 1996, 1998
- U.W. ASCE Student Chapter 1996 Outstanding Professor Award, 1998 Outstanding Professor Award, 1999 Outstanding Professor Award, Fall 2004 Outstanding Professor Award, Spring 2005 Outstanding Professor Award, Fall 2005 Outstanding Professor Award
- L. J. Markwardt Wood Engineering Award presented by the Forest Products Society, 1992
- L. J. Markwardt Wood Engineering Award presented by the Forest Products Society, 1997
- Fellow, University of Wisconsin-Madison Teaching Academy, April 2001
- Chancellor's Distinguished Teaching Award, Univ. of Wisconsin-Madison, April 2002

CERTIFICATION:

- Professional Engineer, Wisconsin - E-24371

FORMAL COURSES TAUGHT AND STUDENT MENTORING:

CEE 442 = Wood Structures
CEE 340 = Structural Analysis *(required undergraduate course)*
CEE 395 = Materials for Constructed Facilities *(required undergraduate course)*
CEE 440 = Structural Analysis II
CEE 540 = Structural Analysis III
CEE 639 = Special Topics: Computer-Aided Design of Facilities
CEE 649 = Special Topics: Advanced Wood Structures
CEE 649 = Special Topics: Fire Resistant Design in Building Construction
CEE 740 = Advanced Topics in Structural Analysis

Graduate advisor to approximately 60 graduate students since 1985

PROFESSIONAL SERVICE AND MEMBERSHIPS:

- American Lumber Standard Committee - US Dept. of Commerce - Member representing engineers
  National Grading Rule Committee representing engineers
  NGR Subcommittee on Limited Wane Grades - 1998-2000
  ALSC Officer Nominating Subcommittee - 2000, 2001, 2002, 2004, 2005

- American National Standards Institute Committee A14.4 Wood Job-Made Ladders, Chair
- American Wood Council - Wood Design Standards Committee, 2000-present
- International Building Code Review Advisory Committee -
  State of Wisconsin, Dept. of Commerce - 1999, 2004, 2005
- Forest Products Society - Member
- Society of Wood Science and Technology - Member
- American Society for Engineering Education - Member
- American Society of Civil Engineers and Structural Engineering Institute - Member
  Chair, Structural Engineering Institute's Committee on Wood 1997-2000
  Associate Editor, *Journal of Structural Engineering* 1991-1994
  Chair, Subcommittee on Timber Engineering Software 1995-1997
  Control Grp Member of Committee on Fire Protection 1994-1997
  Committee on Fire Protection 1994 - present
  SEI Design of Engineered Wood Construction Standards Committee 1999-present
- American Society for Testing and Materials - Member
  ASTM Committee D7 on Wood - Vice Chair for NonProducers, 2005 and Chair, 2005-present
  Subcommittee D07.05.03 Repetitive Use Factors
- Truss Plate Institute -
  - TPI Technical Advisory Committee - 2003-present (the only non-industry member, by invitation)
  - TPI-1 2002 Project Committee 1999-present
  - TPI-2 Project Committee 1999-2003
- Wood Truss Council of America - Engineering Review Committee - 1996-present
- *Structural Engineering Review*, International Journal of Structural Engineering,
  Member of the Editorial Board 1991-1995
- American Concrete Institute - Member
- Faculty Affiliate - Colorado State University 1994-1996

Reviewer/Referee/Panel Member for:

Wood and Fiber Science (reviewer)
Forest Products Journal (reviewer)
ASCE Journal of Structural Engineering (reviewer)
Structural Engineering Review (reviewer)
SFPE Journal of Fire Protection Engineering (reviewer)
Holzforschung (reviewer)
Fire and Materials (reviewer)
Wood and Fiber Science (reviewer)
USDA Forest Products Laboratory Research Publications (reviewer)
USDA Competitive Grants Program (Panel member and reviewer)
USDA Small Business Innovation Research Program (reviewer)
National Science Foundation (Panel member, reviewer)
National Science Foundation EPSCoR Program (Panel member)
National Science Foundation Small Business Innovation Research Program (reviewer)
ASCE Structures Congress Proceedings (reviewer)
West Educational Publishing (reviewer)
Prentice Hall (reviewer)

UNIVERSITY SERVICE:

- Wisconsin Structures and Materials Testing Laboratory Faculty Advisory Committee - 1985 - present
  Chair of Faculty Advisory Committee - 1990 - present
- Ad Hoc Committee on Ethics, Ethnics, and Social Responsibility - 1989
- College of Engineering Associate Dean of Research Screening Committee - 1989
- Wendt Engineering Library - Faculty Advisory Committee - 1989 - 1996
  Chair of Faculty Advisory Committee - 1995 - 1996
- Wendt Engineering Library - Associate Director Search & Screen Committee - 1990
- Wendt Engineering Library - Director Search & Screen Committee - 1991
- College of Engineering Physical Testing Lab. Reorganization Committee - Chair - 1995
- Conflict of Interest Oversight Committee - 1995 - 1997
- UW 10 Year Review Committee of the Department of Engineering Physics - Chair - 2000
- Physical Sciences Executive Committee for the Univ. of Wisconsin-Madison - 2000, Vice Chair - 2001, Chair - 2002
- UW System Review of MS/PhD Degrees in Geological Engineering - 2001
- Univ. of Wisconsin-Madison University Committee (6 member Exec. Committee of the Faculty Senate 2004-2007)
- University of Wisconsin-Madison Provost Search and Screen Committee - 2005
- Various CEE Department Assignments including: Associate Chair of CEE - Constructed Facilities Division 1998-2000, 2003-2004, CEE Merit Salary Increase Committee - 1992-93, 93-94, 94-95, 95-96, 97-98, 01-02, 02-03, 03-04, 05-06 and others. These are elected positions.

CONSULTING:

- Truss Plate Institute
- Various Legal Firms
- General Casualty Insurance
- Manitowoc Crane Company
- Weyerhaeuser Company
- Wood Products Promotion Council

PATENTS :

United States Patent 6,293,152, September 25, 2001, Method for determining twist potential in wood

United States Patent 6,305,224, October 23, 2001, Method for determining warp potential in wood

United States Patent 6,308,571, October 30, 2001, Method for determining crook potential in wood

PUBLICATIONS :

Refereed Papers

1. Cramer, S. M. and Goodman, J. R., "Model for Stress Analysis and Strength Prediction of Lumber," *Wood and Fiber Science*, Vol. 15, No. 4, Oct. 1983, pp. 338-349.

2. Cramer, S. M. and Goodman, J. R., "Failure Modeling: A Basis for the Strength Prediction of Lumber," *Wood and Fiber Science*, Vol. 18, No. 3, July 1986, pp. 446-459.

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4. Cramer, S. M. and Pugel, A. D., "Compact Shear Specimen for Wood Mode II Fracture Investigations," *International Journal of Fracture*, Vol. 35, 1987, pp. 163-174.

5. Washa, G. W., Saemann, J. C. and Cramer, S. M., "Fifty Year Properties of Concrete Made in 1937," *American Concrete Institute Materials Journal*, Vol. 86, No. 4, July/Aug. 1989.

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7. Bohnhoff, D., Cramer, S. M., Moody, R. and Cramer, C. O., "Modeling Vertically Laminated Timber," *ASCE Journal of Structural Engineering*, Oct. 1989, 115(10): 2661-1679.

8. Cramer, S. M. and McDonald, K. M., "Predicting Lumber Tensile Stiffness and Strength with Local Grain Angle Measurements and Failure Analysis," *Wood and Fiber Science*, 21(4), 1989, 393-410.

9. Stahl, D. C., Cramer, S. M., and McDonald, K. M., "Modeling the Effect of Out-of-Plane Fiber Orientation in Lumber Specimens," *Wood and Fiber Science*, 22(2), April 1990, 173-192.

10. Cramer, S. M. and Fohrell, W. B., "Method of Simulating the Tension Performance of Lumber Members," *ASCE Journal of Structural Engineering,* 116(10), Oct. 1990, 2729-2746.

11. Cramer, S. M., Shrestha, D., and Fohrell, W. B., "Theoretical Consideration of Metal-Plate-Connected Wood-Splice Joints," *ASCE Journal of Structural Engineering*, 116(12), Dec. 1990, 3458-3474.

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13. White, R. H., Cramer, S. M. and Shrestha, D. K., "Fire Endurance Model for a Metal-Plate-Connected Wood Truss," Res. Pap. FPL-RP-522, USDA Forest Service, Forest Products Lab., July 1993, 12 pgs.

14. Cramer, S. M., Shrestha, D. K., and Mtenga, P. V., "Computation of Member Forces in Metal Plate Connected Wood Trusses," *Structural Engineering Review*, Vol. 5, No. 3, 1993, pp. 209-217.

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Exposed to Pyrolytic Temperatures," *Fire and Materials*, Wiley, Vol. 18, 1994, pp. 211-220.

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21. Stahl, D. Cramer, S., and Wolfe, R. "Behavior of Metal Plate Connected Trusses with Square-End Webs," *Forest Products Journal*, 46(6), 1996, pp. 78-84.

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27. Polley, C., Cramer, S.M., and de la Cruz, R.V. "Prospects and Challenges for Using Waster Glass as an Aggregate in Portland Cement Concrete" *Journal of Materials in Civil Engineering*, ASCE, Vol. 10, No. 4, Nov. 1998.

28. Stahl, D.C. and Cramer, S.M. "A Three-Dimensional Network Model for a Low Density Fibrous Composite" Journal of Engineering Materials and Technology, ASME, Vol. 120, April 1998, pp. 126-130.

29. Saliklis, E., Cramer, S. and Hermanson, J. "Measuring the Triaxial Load-Deformation Response of Orthotropic Materials Subjected to Large and Small Strains Regime" *Journal of Testing and*

Evaluation, Vol. 26, No. 5, ASTM, Sept. 1998, pp. 444-454.

30. Peyer, S. and Cramer, S. “Behavior of Nailed Connections at Elevated Temperatures” *Wood and Fiber Science*, Vol. 31, No. 3, July 1999, pp 264-276.

31. Cramer, S. and Carpenter, A. “Influence of Total Aggregate Gradation on Freeze-thaw Durability and Other Performance Measures of Paving Concrete” *Transportation Research Record No. 1688, Concrete in Pavement and Structures, Materials and Construction,* 1999, pp.1-8.

32. Carpenter, A. and Cramer, S. “Mitigation of ASR in Pavement Patch Concrete that Incorporates Highly Reactive Fine Aggregate” *Transportation Research Record No. 1688, Concrete in Pavement and Structures, Materials and Construction,* 1999, pp.60-67.

33. Cramer, S., Drozdek, J., and Wolfe, R. “Load Sharing Effects in Light-Frame Wood Truss Assemblies” *J. of Structural Engineering*, Vol. 126, No.12, Dec. 2000, pp. 1388-1394.

34. Falk, R., Vos, D., Cramer, S. and English, B. “Performance of Fasteners in Wood Flour-Thermoplastic Composite Panels” *Forest Products Journal,* Vol. 51, No. 1, Jan. 2001, pp. 55-61.

35. Cramer, S.M. “Expectations Regarding Fire Performance and Building Design” *Wood Design Focus*, Volume 11, No. 2, Summer 2000, pp. 7-12.

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40. Cramer, S. “Structural Design and Materials - Research Needed to Reinvent Housing in the United States” Proceedings of the NSF Housing Research Agenda Workshop, February 12-14, 2004, Orlando, FL., Eds Syal, M., Hastak, M. And Mullens, M Vol. , published by the Dept. Housing and Urban Development.

41. Oleson, J., Brandon, C., Cramer, S., Cucitore, R., Gotti, E., Hohlfelder, R. “The ROMACONS Project: A Contribution to the Historical and Engineering Analysis of Hydraulic Concrete in Roman Maritime Structures” *International Journal of Naval Archeology*, 33(2), Oct. 2004, 199-229.

42. Syal, M., Hastak, M., Mullens, M., Cramer, S., Burnett, E., Koebel, T., O’Brien, M., and Martin, C. “Housing Research Agenda for NSF-PATH” *Journal of Architectural Engineering*, 11(1) , March 2005, 1-7.

43. Cramer, S., Kretschmann, D., Lakes, R., and Schmidt, T. “Earlywood and Latewood Elastic

Properties in Loblolly Pine," *Holzforschung*, Vol 59, 2005, pp 531-538.

Conference Papers and Other Nonrefereed Publications

1. Cramer, S. M. and Goodman, J. R., "Modeling Material Failure with a Vectorized Routine," *Proceedings of the NASA/Goddard-CDC CYBER 200 Applications Seminar*, NASA Conference Publication 2295, 1983.

2. Cramer, S. M. and Goodman, J. R., "Predicting Tensile Strength of Lumber," *Proceedings of the Fifth Symposium on Nondestructive Testing of Wood*, Washington State University, Pullman, WA, 1985.

3. McDonald, K. A., Cramer, S. M., and Bendtwen, B. A., "Research Progress in Modeling Tensile Strength of Lumber from Localized Slope of Grain," *Proceedings of the Sixth Symposium on Nondestructive Testing of Wood*, Washington State University, Pullman, WA, 1986.

4. Cramer, S. M. and Goodman, J. R., "Model for Stress Analysis and Strength Prediction of Lumber," Presented at the 1982 Annual Meeting of the Forest Products Research Society, New Orleans, LA, June 1982.

5. Cramer, S. M. and Goodman, J. R., "Strength Model for Wood Structural Members," *Proceedings of the Eighth Conference on Electronic Computation*, American Society of Civil Engineers, Structural Division, 1983.

6. Cramer, S. M. and Goodman, J. R., "Failure Modeling: A Basis for the Strength Prediction of Lumber," Presented at the 1985 Annual Meeting of the Forest Products Research Society, Orlando, FL, June 1985.

7. Cramer, S. M. and Patton-Mallory, M., "Fracture Mechanics Applied to Wood Products: An Overview," Presented at the 1985 Annual Meeting of the Forest Products Research Society, Orlando, FL, June 1985.

8. Bohnhoff, D., Cramer, S., Moody, R. and Cramer, C., "Modeling Vertically Laminated Wood Members," Presented and distributed at the 1987 International Meeting of the American Society of Agricultural Engineers.

9. Cramer, S. M., Wolfe, R., and Steigerwald, J., "Modeling Load Distribution in Light Framer Roof Systems," Presented and distributed at the 1987 International Meeting of the American Society of Agricultural Engineers.

10. McDonald, K. A., Cramer, S. M., and Bendtsen, B. A., "Using Local Slope of Grain to Predict Tensile Strength," Presented at the 41st Annual Forest Products Research Society Meeting, Louisville, KY, 1986.

11. Cramer, S. M., Stahl, D. C., Fohrell, W. B. and McDonald, K. A., "Exploring the Relationship Between Local Grain Angle and Initial Fracture in Lumber Subject to Tensile Load," *Proceedings of the 1988 International Conference on Timber Engineering*, Sept. 1988 in Seattle, WA, Published by the Forest Products Research Society.

12. Cramer, S. M., Wolfe, R. W. and Peyrot, A., "Modeling Roof Systems for Reliability Analysis," *Proceedings of the 1988 International Conference on Timber Engineering*, Sept. 1988 in Seattle, WA, Published by the Forest Products Research Society.

13. Wolfe, R. W., LaBissoniere, T. and Cramer, S. M., "Performance Tests of Light-Frame Roof Assemblies," *Proceedings of the 1988 International Conference on Timber Engineering*, Sept. 1988 in Seattle, WA, Published by the Forest Products Research Society.

14. Cramer, S. M. an d Fohrell, W. B., "Method for Simulating the Tension Performance of Lumber Members," *Proceedings of the Symposium on Mechanics of Cellulosic and Polymeric Materials*, American Society of Mechanical Engineers, 1989, pp. 193-200.

15. Hermanson, J., Johnson, J. and Cramer, S. M., "A Stress Singularity Due to the Grain Pattern around a Knot," Presented at the 47th Annual Forest Products Research Society Meeting, Charleston, SC, 1992.

16. White, R. H., Cramer, S. M., and Shrestha, D. K., "Fire Endurance Model for Metal-Plate-Connected Wood Trusses," *Proceedings of the First Fire and Materials Conference*, Interscience Communications Ltd., London, UK, Sept. 1992.

17. Cramer, S. M., Shrestha, D. K. and White, R. H., "Fire Endurance Model for a Metal-Plate-Connected Wood Truss," *Structural Engineering in Natural Hazards Mitigation*, Proceedings of papers presented at Structures Congress '93, American Society of Civil Engineers, New York, NY, 1993, 472-477.

18. Cramer, S. M. and White, J., "Flux-Time Exposure - A Fire Endurance Measure for Lumber," *Proceedings of the 2nd International Fire and Materials Conference*, Interscience Communications Ltd., London, UK, Sept. 1993.

19. Suryoatmono, B., Cramer, S., Shi, Y. and McDonald, K. A., "Within-Board Lumber Density Variations from Digital X-Ray Images," *Proceedings of the 9th International Symposium on Nondestructive Testing of Wood*, Forest Products Society, Madison, WI, 1994, pp. 168-175.

20. Cramer, S. and Bakke, P., "Potential Use of Cupola Slag as Road Construction Material," *Proceedings of the International Cupola Conference*, American Foundrymen's Society, Inc., 1994, pp. 113-122.

21. White, R. and Cramer, S., "Improving the Fire Endurance of Wood Truss Systems," Proceedings of the 1994 Pacific Timber Engineering Conference, Vol. 1, Timber Research and Development Advisory Council, Queensland, Australia, 1994, pp. 582-589.

22. Cramer, S., "Fire Endurance Modeling of Wood Floor/Ceiling Assemblies," Proceedings of the Fourth International Fire and Materials Conference, InterScience Communications Limited, London, England, 1995, pp. 105-114.

23. Cramer, S. M., Hermanson, J. C., and McMurtry, W. M., "Crush Performance of Redwood for Developing Design Procedures for Impact Limiters," Proceedings of 11th International Conference on the Packaging and Transportation of Radioactive Materials (PATRAM '95), Vol. 2, Social & Scientific Systems, Inc., Bethesda, MD, pp. 875-882.

24. Wolfe, R.W. and Cramer, S.M. "Repetitive Member Adjustment for Wood Structural Design," Building an International Community of Structural Engineers, Proceedings of Structures Congress XIV, Vol. 2. American Society of Civil Engineers, New York, New York, 1996, pp. 804-811.

25. Cramer, S.M., Shi, Y., and McDonald, K. "Fracture Modeling of Lumber Containing Multiple Knots," Proceedings of the International Wood Engineering Conference '96, New Orleans, LA, Oct. 27-Nov. 1, 1996, Vol. 4, pp. 4-288 - 4-294.

26. Cramer, S.M., and White R.H. "Fire Endurance Model for Wood Structural Systems," Proceedings of the International Wood Engineering Conference '96, New Orleans, LA, Oct. 27-Nov. 1, 1996.Vol. 2, pp. 2-249 - 2-256.

27. Cramer, S.M. and White, R.H. "Fire Performance Issues," Proceedings of the Workshop on Wood Engineering in the 21st Century: Research Needs and Goals. ASCE Structural Engineering Institute. 1997. 12 pgs.

28. Cramer, S. and Wheat, D. "Where Can I Find Wood LRFD Instruction?" Proceedings of the 1999 SEI Structures Congress. ASCE 1999. 6 pgs.

29. Walls, R. A. and Cramer, S. "Effects of Water-Cementitious Materials Ratio and Air Content on the Freeze-Thaw Durability of Portland Cement - Preliminary Findings" Preprint for the 79th Annual Meeting of the Transportation Research Board, January 2000.

30. Falk, R., Vos, D. and Cramer, S. "The Comparative Performance of Wood fiber-Plastic and Wood-based Panels," Proceedings of the 5th International Conference on Wood Fiber-Plastic Composites, Forest Products Society. 2000.

31. Cramer, S.M. and Drozdek, J. "Load Sharing in Metal-Plate Connected Wood Truss Assemblies" Proceedings of the World Conference on Timber Engineering, Dept. of Wood Science, Univ. of British Columbia, Vancouver, BC, Canada. July 2000.

32. Cramer, S.M. and Kennedy, S.A. "Analysis of Wood Assemblies with Similar and Dissimilar Trusses", 2001 ASCE SEI Structures Congress Proceedings, May 2001.

33. Cramer, S.M. "Mix Parameters Controlling the Extended Freeze-thaw Durability of Concrete Containing Cementitious Additives," Preprint for the 81st Annual Meeting of the Transportation Research Board, In-press as of November 2001.

34. Grundahl, K. and Cramer, S. "Knowledge is Power - Introducing a New Quality Standard", *Structural Building Components,* November 2001, pg. 12-17.

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Unpublished Technical Reports: 20+ (not listed)

Book Reviews

1. Cramer, S.M. On *Science and Technology of Wood - Structure, Properties, Utilization* by George Tsoumis, Van Nostrand Reinhold, 1991. Review appearing in *Structural Engineering Review,* Vol. 5, No. 1, pp. 81-83, 1993.

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PROFESSIONAL EXPERIENCE

1974-1979	Assistant Professor	University of Wisconsin-Madison, Civil & Environ. Engr.
1979-1983	Associate Professor	University of Wisconsin-Madison, Civil & Environ. Engr.
1983-Present	Professor	University of Wisconsin-Madison, Civil & Environ. Engr.
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PROFESSIONAL ACTIVITIES

Editorial Board – *Journal of Porous Materials*.
External Peer Reviewer – DOE, EPA, NSF, WERF.
Science Alliance Advisory Board University of Wisconsin – Whitewater, 2004-Present.
Fulbright Fellow, CIEMAT, Madrid, Spain, 2002.
Visiting Professor, Institute of Ceramics and Glass, CSIC, Madrid, Spain, 1988-89.
Visiting Professor, Groupe de Physico-Chimie Minerale et de Catalyse, Universite Catholique de Louvain, Louvain-la Neuve, Belgium, 1980-81.

SELECTED PUBLICATIONS (FROM 159)

Twesme, T.M., **Tompkins, D.T**., Anderson, M.A., Root, T.W., (2006), Photocatalytic oxidation of low molecular weight alkanes: Observations with ZrO_2–TiO_2 supported thin films, *Applied Catalysis B: Environ.*, 2006, in press.

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Brownson, J.R.S., Lee, T.J. and Anderson, M.A. (2005). Surface re-esterification and photo sintering of titania xerogel thin films. Chemistry of Materials, (11), 3025-3030.

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University of Madrid, Spain	MS	1970	Chemistry
University of Madrid, Spain	Ph.D.	1974	Chemistry
Consejo Superior de Investigaciones Cientificas, Spain	Postdoc	1975-76	Chemistry
Macauley Institute for Soil Research, Scotland	Postdoc	1977-78	Chemistry
University Catholique de Louvain, Belgium	Postdoc	1979-80	Chemistry

Professional Experience:

1981-1988. Associate Scientist, Water Science & Engineering Laboratory, Department of Civil and Environmental Engineering, University of Wisconsin-Madison.

1989-Present. Senior Scientist, Water Science & Engineering Laboratory, Department of Civil and Environmental Engineering, University of Wisconsin-Madison.

Awards:

University of Wisconsin – Madison Academic Staff Excellence Award, 2005.
Services de la Politique Scientifique Belge Postdoctoral Fellow, 1979-80.
The Royal Society of London Postdoctoral Fellow, 1977-78

Relevant Publications:

1. Vichi F.M., **M.I. Tejedor-Tejedor**, and M.A. Anderson. 2005. Proton conductivity in tungsten and antimony-modified titania ceramics prepared by the sol-gel method. *Solid State Ionics*, **176(9-10)**:973-978. *(This paper showed how the proton conductivities of* TiO_2 *membranes used in inorganic proton exchange membrane fuel cells could be modified by doping the surface of the membranes with selected metals.)*

2. Zhang R., **M.I. Tejedor**, C.A. Grimes, and M.A. Anderson. 2002. Optimizing nanoporous metal oxide coatings for use in magnetoelastic resonance-based sensors. *Sensors*, **2**:331-338. *(This paper indicated how a variety of nanoparticulate metal oxides prepared by sol-gel processing could be modified and selected for use in a gas-phase sensor.)*

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Other Significant Publications:

1. Zorn M.E., K.A. Rahne, **M.I. Tejedor-Tejedor**, and C.A. Grimes. 2003. Characterization of gas-phase adsorption on metal oxide thin films using a magnetoelastic resonance microbalance. *Anal. Chem.*, **75**:6223-6230.
2. Coronado J.M., S. Kataoka, **M.I. Tejedor-Tejedor**, and M.A. Anderson. 2003. Dynamic phenomena during the photocatalytic oxidation of ethanol and acetone over nanocrystalline TiO_2: simultaneous FTIR analysis of gas and surface species. *J. Catal.*, **219**:219-230.
3. Miller L.W., **M.I. Tejedor-Tejedor**, B.P. Nelson, and M.A. Anderson. 1999. Mesoporous metal oxide semiconductor-clad waveguides. *J. Phys. Chem.*, **103[40]**:8490-8492.
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7. Chu L., **M.I. Tejedor-Tejedor**, and M.A. Anderson. 1997. Particulate sol-gel route for microporous silica gels. *Microporous Mater.*, **8**:207-213.
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9. Tickanen L.D., **M.I. Tejedor-Tejedor**, and M.A. Anderson. 1991. Quantitative characterization of aqueous suspensions using attenuated total reflection Fourier transform infrared spectroscopy: Influence of internal reflection element-particle interactions on spectral absorbance values. *Langmuir*, **7**:451-456.
10. **Tejedor-Tejedor M.I.** and M.A. Anderson. 1990. Protonation of phosphate on the surface of goethite as studied by CIR-FTIR and electrophoretic mobility. *Langmuir*, **6**:602-611.