1995 116615
N95-23032

Fire Hazard Considerations for Composites in Vehicle Design

Rex B. Gordon, P.E.

ABSTRACT

Military ground vehicles fires are a significant cause of system loss, equipment damage, and crew injury in both combat and non-combat situations. During combat, the abi..ty to successfully fight an internal fire, without losing fighting and mobility capabilities, is often the key to crew survival and mission success. In addition to enemy hits in combat, vehicle fires are initiated by electrical system failures, fuel line leaks, munitions mishaps and improper personnel actions. If not controlled, such fires can spread to other areas of the vehicle, causing extensive damage and the potential for personnel injury and death. The inherent fire safety characteristics (i.e. ignitability, flame spread and decomposition products) of polymerics located within internal compartments of these vehicles play a major roll in determining rather a newly started fire becomes a fizzle or a catastrophe.

This paper addresses a systems approach to assuring optimum vehicle fire safety during the design phase of complex vehicle systems utilizing extensive uses of composites, plastics and related materials. It provides practical means for defining the potential fire hazard risks during a conceptual design phase, and criteria for the selection of composite materials based on its fire safety characteristics.

THE FIRE SAFETY DILEMMA

Ground combat vehicle designers find many potential advantages in selecting composites and other polymeric materials in place of traditional metals. These include enhanced crew protection from external ballistic hits in addition to reduced weight and manufacturing costs advantages. However, such usage may inadvertently create additional fire safety related hazard risks which need to be properly managed during the design process.

Today, most U.S..Army and Marine ground combat vehicles are equipped with electronic infra-red (IR) hydrocarbon fuel fire detection and fuel-mist fireball explosion suppression systems. During live-fire testing, these automatic fire suppression systems (AFSS) have been able to detect a growing fuel mist fireball resulting from a shaped charge penetration of a diesel fuel tank, and release pressurized Halon 1301 agent, in a manner that often suppresses the fireball in less than a quarter of a second - quick enough to prevent serious burns on exposed skin of passengers and crew of the vehicle. Although essential in crew protection from the penetrated fuel cell / fuel mist fireball scenario, these AFSS units are not fully optimized for other, more frequent fire scenarios such as accidental fuel line leakage in engine and crew heater locations. In addition, when used to extinguish a fire, high concentrations of acid gases are formed from the decomposition of the Halon agent. These vapors are very irritating and toxic, and must be evacuated quickly, to provide survivable breathing air for crew members and troops unable to quickly leave the vehicle.

Army Safety Center reports indicate that during the 10 year period 1974 -1984, some 213 non-combat tracked vehicle fires occurred, resulting in 2 fatal and 30 serious injuries. The material losses were estimated at 12.7 million (1984 dollars) Army safety investigators have indicated that these reported accidents represented perhaps only a fourth or less of the actual (i.e. reported and unreported) fire incidents occurring in the field. Sampling of the accident data base subsequent to the 1984 report indicates that the frequency and cost impact of these non-combat fires are increasing as more sophisticated and expensive vehicles are entering the inventory. A non-combat vehicle fire incident occurring in South West Asia, involving multiple parked vehicles, accounted for equipment damage which was estimated to be some 4 to 5 times that reported during the entire ten year period of 1974-1984. From the data reviewed, non-combat fire continue to constitute a significant safety concern, in fielded tracked vehicles.

In the opinion of this author, the proper utilization of the systems engineering approach in the area of an integrated passive and active fire safety is the most cost effective approach for improving fire safety in new or modified ground combat vehicles. It is suggested that this goal should receive a higher priority for development funding in this time of ever reduced combat vehicle resources. Vehicles which are able to avoid severe damage due to onboard fires, for their entire military life, are available for essential unit training to engage in critical combat when called upon. It is generally agreed that crews that have confidence in the safety features of their vehicles typically perform better in hazardous situations. Trained troop and crews are valuable combat assets which must be protected from accidental injury where ever feasible.

In view of these factors, it would be expected that combat vehicle developers would have an increased interest to improve fire safety through inherent design (passive) and in the research and development of improved AFSS that do not relay on the use of environmentally harmful Halon, a chemical which has been ordered to be phased out of use by DoD policy. Unfortunately, Army activities having primary technical expertise in this area have been limited in effectiveness due to shortage of funding earmarked for this area. The limited research conducted in the passive fire safety area have not been initiated under a long range systematic plan, but primarily to address a limited specific one time issue for a specific project.. Consequently, there is only very limited data available for formulating detailed design oriented fire safety criteria which can be provided to the designer, even if such action were to be given priority by the system developer.

Traditionally, ground combat vehicle designs have emphasized mobility, offensive firepower, hit avoidance and armor protection, rather than behind armor / fire safety characteristics, during conceptual design phases. This weighting in system design priorities is consistent with the typical overall mission objectives as defined by the using activity when a new or improved weapon system is being developed. Although safety and crew survivability is often given a high weighting in a list of desirable objectives that the design is to provide, there are usually limited "hard" requirements that accompany this general statement of desirability. Thus, in practice, design development teams often find they must compromise on the "softer" safety related design requirements (i.e. minimize hazards to crew) in order to satisfy the more readily quantifiable hard requirements (i.e. speed, range, time on target, etc.)

What then are ways to resolve this dilemma? The author suggests that a more focused attention to the systems engineering aspects in this area is the best solution. Certain new vehicle development activities have incorporated such efforts as an integrated aspect of those analyses and technical trade-offs typically occurring as part of the design process. This approach involve system oriented fire risk assessments for defining effective design approaches, material selection criteria and effective fire safety requirements for integrated passive and active of fire safety for new and modified vehicles In its more effective implementation, this approach includes: (1) the conceptual layout of the various vehicle compartments so that ammunition, liquid fuel tanks and lines are separated from crew areas, (2) selection of the optimum fire detection / suppression system for each compartment, based on the significant fire scenarios applicable for al l life cycle phases, and (3) the selection of materials to be incorporated into the vehicle design with fire safety considerations a paramount consideration.

The remainder of this paper will be primarily oriented toward this last noted systems engineering fire safety approach, i.e. the proper selection of fire safe, non-metallic materials in vehicle design activities.

COMPOSITES, PLASTICS AND VEHICLE FIRE SAFETY

Traditional fuel sources for vehicle fires include heated fuel and hydraulic fluids, electrical motors and wiring, on-board munitions, personal gear and other stored combustibles. As their application increases, polymers will become a significant addition to this listing of potential fire related fuel sources. Plastic components and composite material systems, comprised of high strength fibers in organic resin matrices are finding increasing acceptance as viable solutions to demands for improved battlefield performance. Vehicle development efforts are now focusing on hulls and turrets made primarily of composites. Such vehicles can provide significant weight savings, as well as improved ballistic protection, reduced radar signature, and other desirable survivability characteristics.

Given sufficient oxygen and heat input, most organic polymers will burn more readily than metal Since full avoidance of fire risk concerns is not feasible, intelligent trade-offs between safety, utility, and costs are necessary during the material selection process of the design phase of a project.. It is primarily when polymers are applied in an enclosed environment, where the increased fuel loading is provided in a small inhabited spaces, does the fire safety issue become acute. In addition to ground combat vehicles, such acute fire safety concerns exist in certain buildings, submarines, manned space craft, ships, rapid transit vehicles, and aircraft. Lessons learned from bad experiences and successful design approaches in these other acute fire safety buildings and systems should be utilized be those assigned fire safety responsibility in the developmental phases of a new or modified ground combat vehicles - if potential fire safety risks to be cost effectively controlled.

As previously noted, the most effective approach to fire safety during vehicle design to address this issue in a total systems (i.e. an integrated passive and active fire safety approach) rather than as separate, unrelated elements. The selection of a non-metallic material needs to suitably consider the fire safety aspects of the material, but this consideration needs to influenced by the size, shape location and adjacent ignition potentials of the compartment in which it is to be used in the vehicle.

FIRE SAFETY CONSIDERATIONS IN MATERIAL SELECTION.

When addressing the fire safety concerns presented from the introduction of a new polymer into a vehicle or component design, the typical approach taken by material experts (and / or Military Specifications) is to specify one or more standard laboratory flammability test method to be performed on a designated sample of the candidate material. It is obviously less expensive and quicker to specify and conduct sample size testing, rather than conduct a full scale vehicle fire testing. The fire safety concern is related to the appropriateness of this type testing to actual hazard reduction during vehicle operations when human lives are at risk.

Most standard flammability test methods involve repeatable, small scale material sample testing in a laboratory apparatus designed to reduce potential environmental variables. A typical flammability test involves preparing a strip of material sample in a prescribed orientation (horizontal, vertical or at an angle), placing a controlled heat source at one end for a specified time and noting the burn length, duration, and melting characteristics of the sample. In some test methods, (i.e. the UL 94 series) the accept reject criteria is included, but in most ASTM test methods this is an open issue, which must be specified by some one for the specific application.

Although repeatable and fairly inexpensive, there is a serious shortcoming of these types of test methods. They are not able to fully predict or describe with certainty the burning characteristics of plastics products under actual fire conditions in the vehicle The size, location, ratio of exposed surface, and relation to adjacent fuels and fire threats are systems issues that need to be addressed during the material selection process. . A key factors in this area is the energy feedback issue. In the combustion of a polymeric material, the thermal energy feedback from any adjacent fire or other high temperature source can result in pyrolysis of the material surface to provide a continuing supply of gaseous fuel to the flame.

Ambient temperature sample testing may not adequately address this thermal feedback risk issue. In actual fire scenarios, the rate of burning is directly related to the magnitude of this energy feedback and the intensity of combustion. In the typical small scale test method (such as the UL 94 series), most of the energy of combustion is dissipated in the rising convective plume and through radiation to the cool surroundings. In a real fire, on the other hand, energy exchange between adjacent fuel surfaces and radiation from the heated surroundings greatly increases the energy feedback and the intensity of combustion.

Another concern in evaluating small scale flammability testing results is the interrelated safety issue of the decomposition products. These issues include reduced visibility due to smoke (hamper safe vehicle operations and exiting hazard area) and the health hazard issues. There are many references in the fire safety literature that relate these combustion product risk factors as the leading cause of injury and fatalities in fires involving polymerics

To overcome this inherent shortcoming, activities concerned with establishing specific fire safety material criteria for a given application are tending toward testing methods that provide a radiant flux input, combined with combustion product evaluations. Another key factor is the utilization of full scale fire scenario testing results to better evaluate the effectiveness of the small scale acceptance criteria selection criteria.

A revision to the Federal Aviation Administration (FAA) air worthiness standards for materials used in aircraft interiors (14 CFR 25.853) provides a good illustration in an application somewhat related to fire safety issues associated with ground combat vehicles. In this example, the selection of an improved flammability test method was made from correlation studies of data from candidate material testing and full scale fire testing. Studies of actual aircraft fire incidents indicated that a post crash landing fuel fire located external to an opening in the aircraft passenger cabin provided the most likely severe fire accident scenario.

Full scale testing of alternate composite interior surface materials (partitions, sidewalls, stowage bins) was conducted in a C-133 wide body crew compartment converted for fire testing use. A large fuel fire was initiated external to the cabin and cameras monitored that reaction of the composite test panels. It was found that the different composite materials presented significant differences in both delay times to flash-over and toxic gas levels. This was not as evident from the normal laboratory burn rate testing results.

Experimentation showed that the best correlation between actual full scale fire testing findings and laboratory testing methods was through use of a modified version of the Ohio State Univ. (OSU) rate of heat release apparatus used in ASTM E 906, Test Method for Heat and Visible Smoke Release Rates for Materials and Products. This is basically a flow through device that measures the heat release rate produced as a function of time by a material subjected to a preset level of radiant heat flux. A significant lessons learned in this activity was the desirability of utilizing results of even limited the full scale testing, when selecting sample testing methods and pass-fail criteria..

FIRE SAFETY PRINCIPLES IN MATERIAL SELECTION

To help satisfy client requests for fire safety guidelines in the selection of polymeric material being considered for application into combat vehicles, the author has formulated the following basic principles in this specific area of concern:

1. The complex interactions between real life vehicle fire scenarios, the specific application of a given material, and fire safety characteristics of the vehicle design dictate that material selection criteria in this area cannot be treated solely in a cookbook manor, but rather by professional prescription, based on systems oriented hazard risk analyses. The common design engineering practice of noting some *mil spec* reference on the drawing, - in anticipation that it will provide adequate flammability criteria requirements, without further analysis, should not be allowed by program management.

2. Fire safety criteria must carefully address the necessary balance between essential performance characteristics (i.e. mechanical loads, durability, etc.) producibility, and flammability. This balance needs to consider the potential product liability risks inherent with the design process (primarily assumed by a private contractor preparing the design) and combat mission requirements of the military customer. Resolution of the often severe conflicts occurring between these two concerns, should involve representative of all parties involved with clear documentation on the technical (not just cost) rationale used.

3. Fire safety criteria formulated for use in material selection during design must be based, to the degree feasible, on the best possible estimate of the most severe credible fire accident scenarios applicable for both combat and non-combat situations. This evaluation is to consider (and influence where possible) all aspects of both the active as well as passive fire hazard reduction provisions of the vehicle system, The material selection criteria thus established should include suitable rationale as to how the criteria is oriented to minimizing the specific risks identified in the worst case fire accident scenario assessments.

4. To reduce the costs associated with performing the fire safety assessments, selected generic material selection criteria should be defined which differentiate between low, mid and high hazard risk applications. The low risk applications can use less extensive small scale tests than the high risk applications. For each type of vehicle system, some standard categories material selection criteria can be established to expedite the design process One example of this "category by hazard risk of the material application in the system" approach is as follows:

Low Risk Applications - The polymeric material, when assembled into the vehicle, will have **no** exposed surface which will be

a. located in any occupied compartment with a total surface area over 5 cm^2, or

b. subject to thermal flux environment (from maintenance process. equipment, combat threat, or accidental mishap) which could heat surface to over 500 degrees F., or

c. used to cover electrical wires subject to carrying <30 volts, or otherwise presents more than a low fire safety risk due to some unusual application consideration...

Moderate Risk Applications - The polymeric material, when assembled into the vehicle, will have **no** exposed surface which will be:

a. located in any occupied compartment with a total surface area over 500 cm^2, or,

b. subject to a thermal flux environment (from maintenance process. equipment, combat threat, or accidental mishap) which could heat surface to over 1000 degrees F., or

c. used to cover electrical wires subject to carrying <140 volts, or otherwise more than a moderate fire safety risk due to some unusual application consideration..

High Risk Application -The polymeric material, when assembled into the vehicle, will present potential fire risks which exceed those defined as low or moderate, or has significant uncertain fire risk considerations which preclude proper assessment without further research and testing. .

5. To date, the only end product use oriented material selection fire safety criteria directly applicable to ground combat vehicles is found in MIL-STD-1180(AT) "Safety Standards for Military Ground Vehicles" dated July 1976. This references Federal Motor Vehicle Safety Standard (FMVSS) No. 302. "Flammability of Interior Materials". This was issued by the DOT in 1975 to provide a minimum standard for interior materials used in passenger vehicles. It was based on a scenario in which a seat cover fire was initiated by a dropped cigarette, and all passengers exit the vehicle within a minute or less. The test will pass a material sample strip, which when held horizontal in a holder, and contacted with a flame at one end, burns no more than 4 inches a minute. It is suggested that this criteria be considered only as an initial screening test requirement, and for low risk applications.

FIRE SAFETY TESTING GUIDELINES AND CRITERIA

With a suitable risk category system established, it is then feasible to define some basic material testing procedures and evaluation guidelines for each risk category. Using the example risk categories noted above the following is one proposed approach:

1. Material testing for fire safety acceptance, are to be performed in accordance with an established fire safety plan, that considers the findings of a vehicle oriented fire risk assessment. Screening test results for selection of polymeric materials shall be evaluated based on fire safety risk categories and how close the samples used for the testing are representative of the actual polymeric item when assembled in the vehicle:

2. Other than for *low risk* applications, materials being considered for use inside the crew compartment are to be evaluated, using existing data, for potential of toxic gas generation upon combustion in worst-case operating scenarios environments. To the extent feasible, materials should be selected which have the least potential health hazard characteristics, using ASTM E-800 as a guide. Where a trade-off between alternate material candidates is involved, weighting should be given to ignition and low flame spread, over smoke and toxic gas characteristics. This weighting approach is based on the fact that since most all plastics release some smoke and toxic decomposition products, the bast way to control these hazards is to reduce the potential for the material to ignite and burn.

3. Material samples or coupons used for fire safety testing should be as representative as feasible of the end use configuration. This includes any surface finishes, thickness, bonding to other materials, configuration orientations, etc. The test plan (as noted above) should always define the detailed description and source of all needed test specimen samples. Where feasible, the manufactured components should be utilized as the source of test samples, rather than a vendor supplied specimen.

4. The following fire safety testing and evaluation criteria developed by the author for a client company's use in this area is summarized below to serve as an example format. The values selected for the accept criteria were adapted from Federal Transit Administration's "Recommended Fire Safety Practices for Transit Bus and Van Materials Selection",. (This document provides one of the most directly related, government agency published fire safety selection criteria, to combat vehicle applications):

FIRE RISK CATEGORY	TEST METHOD	ACCEPT CRITERIA
LOW	FMVSS 302	PASS
MODERATE	UL94 OR ASTM 635	V-1 OR EQUIVALENT
	ASTM E-2863	LOI .21 AT 25^{o} C
	ASTM E-662	<200 DS (100 sec) <400 Ds (240 sec)
HIGH	ASTM E-162	<35 FLAME SPREAD INDEX
	ASTM E-2863	LOI .>27 AT 25^{o} C
	ASTM E-662	<100 DS (100 sec) <200 Ds (240 sec)
	UL 746A (IF MATERIAL IS USED AS ELECTRICAL WIRE / COMPONENT PROTECTION)	PARA 24,25,42, OR 43 AS APPLICABLE

5. The above criteria is an interim guide - developed for use when an immediate design decision is needed. It is recommended that those in the military and industry having fire safety responsibilities for combat vehicle development continue to evaluate the material selection criteria issue through a formal joint DoD / Industry working committee. This committee should be the focal point for summarizing lessons-learned information from existing fire accident reports, and establishing requirements for additional full scale testing in the combat vehicle area to provide better benchmarks for validating any proposed laboratory level sample test accept / reject criteria points. This committee should also have provisions for establishing a database of fire safety testing results by material formulation, so that this information can be used by other making similar material selection trade-offs. In time the data collected from both full scale and laboratory scale testing of polymeric materials being considered for combat vehicle usage could organized in a systematic manor, which would lead to a more standardized and universally applied testing criteria established within the combat vehicle development community - than now exists..

Potential Errors in Respirable Fiber Measurements of Dusts from Composite Manufacturing

Edmund A. Merriman
Product Steward,
DuPont Advanced Fibers Systems

Joseph F. Viskocil
Certified Industrial Hygienist
DuPont Haskell Laboratory for Toxicology and Industrial Medicine

Introduction

- Need Validated Measure of Airborne Respirable Fibers in Composite Plants
- Composite Dusts Have Few Fibers, Much Particulate
- Size, Shape, Conductivity, Density of Non Asbestos Fibers Vary
- Regulators Question Use of Asbestos Methods
- Aim: Validate NIOSH 7400 for Para-Aramids
- Surveying Para-Aramid Fibril Exposures in Composite Workplaces
- Significant for Composite Dust Research

Overview

- Introduction
- Standard Fiber Counting Method – NIOSH 7400
- Valid for Studying Composite Dusts?
- Sources of Errors
- Potential Magnitude of Errors
- Significance for Composite Workplace Surveys
- Continuing Studies

NIOSH 7400

- Designed for Asbestos – Straight, Dense, Rod-Like Fibers
- Draw 2 Liters/Min Workplace Air Through 25mm Diameter Filter
- Filter Segment Mounted on Slide, Cleared to Show Particles
- Respirable Sized Fibers Counted Microscopically for Airborne Fiber Concentration
- Statistically Designed, But Highly Variable (Cv = 40%)

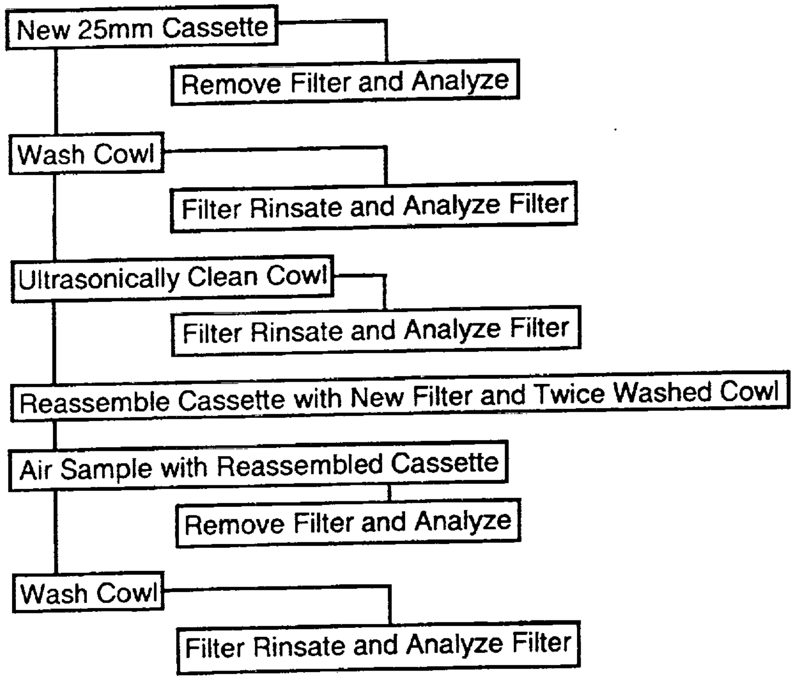
Validity of NIOSH 7400 for Para-Aramids

- Lower Density (1.45 vs. 2.6g/cc)
- Complex Shape – Branched, Ribbon-Like, Curled
- Electrostatically Negative, Easily Charged
- More Likely to Agglomerate

Potential Sources of Air Sampling Error

- Cassette Cowls Could Contribute Non-Aramid Fibrils
  - Known to Contain Fibrils of Countable Size
  - Would Give Positive Bias – Measurements Too High
- Cassette Cowls Could Capture Incoming Fibrils
  - Higher Fiber Charge and Shape Might Favor Adhesion
  - Would Give Negative Bias – Measurements Too Low
- Laboratory Tests Designed to Measure Potential for Both

Cowl Study Test Method



Cowl Rinsing Test Results

(Fibers Per Field)

	Cassettes A avg/med	Cassettes B avg/med	Cassettes C avg/med
From 1st Wash	1.80 0.36	1.30 0.90	0.80 0.17
From 2nd Wash (After Ultrasonic)	2.15 1.23	3.61 1.70	1.14 0.39

Conclusion:
- Ultrasonic Rinsing Needed to Clean Cowls
- Levels Equivalent to >1 Fiber/cc in a 1-hr Test

(10 Cassettes Per Set)

Percent of Sampled Fibrils Caught by Cowl

Ranked by Total Fibrils

% Fibrils on Cowl	Filter f/cc	% Fibrils on Cowl	Filter f/cc
315	0.005	84	0.095
4975	0.005	7	0.374
3932	0.005	16	0.309
2546	0.005	13	0.779
219	0.006	7	0.831
883	0.015	28	0.609
91	0.058	11	0.769
13	0.170	4	6.030

Conclusion: Fibrils Trapped on Cowl More Significant at Lower Airborn Fibril Concentration

Average Respirable Fiber Counts from Fabricating Para-Aramid Composites

Composites Fabrication Operations	Personal f/cc	Area f/cc	Samples P	Samples A
Prepreg Cutting & Laying Up	0.02	—	20	—
Molding	0.01	0.01	11	2
Trimming, Drilling	0.03	0.01	33	13
Sandblasting	0.02	0.01	4	3
Reworking	0.02	0.02	5	3
Waterjet Cutting	0.03	1.88	1	2
Maximum (Between Work and Hood)	0.25			
Field Blanks		0.007	97 Samples	

Conclusion: Para-Aramid Fibril Exposures Well Below 2 f/cc Limit

Significance of Errors for Workplace Monitoring

- Cowl Contributions Can Be Significant at Low Fiber Counts
  - For Research on Fiber Dust, Cowls Must Be Washed
  - Field Blanks Indicate Few of Many Cowl Fibers Reach Filter
- Cowl-Captured P-Aramid Fibrils Significant Only at Low Levels
  - Insignificant Near DuPont Acceptable Exposure Limit (>2 f/cc)
  - Could Slightly Alter Levels Typical of Composite Shops
- No Apparent Effect of Humidity, Though Expected
- NIOSH 7400, Method B Remains Acceptable Monitoring Method

Research Program Continuation

- Examine for Size Bias in Captured Fibrils
- Measure Aerodynamic Diameter of Kevlar® Fibrils
  - Use for Inhalation Deposition Modeling
- Characterize Fibrils and Dust from Composite Operations (with AIA/SACMA ?)