Plastic Failure LABS

**Dr. Duane Priddy** • Founder & CEO

Toll Free USA: 877.668.4345
International: +1.989.385.2355
Email: priddy@plasticfailure.com
Web: www.plasticfailure.com

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**Supplemental Report on the Root Cause of Failure of**
**14" PVC C-905 Buried Force Main Pipeline in Arkansas**

**Executive Summary**

Environmental Resources Management (ERM) contracted Plastic Expert Group & Plastic Failure Labs, Inc. (PEG) to conduct a 3rd party evaluation of a failed section of 14-inch diameter JM Eagle C905 DR32.5 PVC pipe (force main). My CV is included in the Appendix Section. The evaluation was completed and report issued on January 17, 2017. There are four possible causes of PVC bell joints to fracture: defective manufacture, defective installation, defective operation, and exposure to incompatible chemicals (Environmental Stress Cracking (ESC)). The results of our work revealed that the belled pipe joint failed by what is called "Creep Failure". Creep Failure can only occur if the bell joints were not in alignment or if the long term operating pressure of the pipeline was too high. Since the pipeline was operated consistently at normal operating pressure and was not over-pressured, the creep failure could have only been caused by defective installation. Following our work, PSI Lab (PSIL) attempted to rebut that the piping joints were defectively installed by attempting to find incompatible chemicals to blame for the failure. Not only were they unable to find significant concentrations of incompatible chemicals anywhere in the failed piping joints, but their scanning electron microscope (SEM) images of the fracture surface support that the joints failed by creep failure and not by ESC. After further review of the facts in this matter and the PSIL report, PEG strongly disagrees with the opinions of PSIL as follows:

- The morphology of the fracture surface as, revealed in PSIL SEM images, is not consistent with ESC failure.
- Only trace chemicals were found on the fracture surfaces and in the gasket. Trace chemicals are ubiquitous and the trace levels found are insufficient to cause ESC failure of PVC pipe. In fact, most of the trace chemicals found were in the PVC formulation used to manufacture the pipe or else present in the solvent used for the extraction.
- The failure mode is most consistent with "creep failure" and not ESC failure.
- The creep failure resulted from misalignment of the spigot pipe inside the bell.

Sincerely,

*Duane Priddy, Ph.D. / President*

**Rebuttal of PSIL Report**

The PSIL Report (number GBM-120816-1-RP1) claimed the failure of the pipe was due to exposure to environmental stress crack (ESC) agents and was not due to defective installation. The conclusions of the PSIL report presents speculations which are not supported by the evidence as follows:

1. PSIL Report Figures 7 and 8 show SEM images of the fracture surface. Their opinion of the images is that they reveal brittle fracture. Our opinion is the opposite; i.e., the images exhibit clear evidence of microductility, draw, and elongation of microcracks which grew into microvoids followed by ductile deformation as indicated in Figure 1 on the next page of this report.

2. ESC fractures generally exhibit "thumbnail" shaped smooth patterns on the fracture surfaces. Absorption of an incompatible chemical into the wall of the pipe causes plasticization allowing the polymer chains to soften and disentangle from each other.[1] Since the extent of polymer chain entanglement is proportional to PVC pipe strength and ductility, once the plasticized polymer chains disentangle during use, the PVC turns brittle allowing the crack to propagate a short distance before it becomes arrested by ductile material where the chemical has not yet reached. The process then repeats itself over and over forming a series of parallel steps generally referred to as "beach marks." The fracture surfaces shown below in Figure 1 (PSIL Report Figure 8) shows none of these characteristic ESC features.

3. Tensile test and ASTM flattening test results do not support differences in behavior attributable to ESC failure. The PVC material in the pipe is highly ductile and shows no evidence of weakening by absorption of incompatible chemicals. The tensile test results are further supported by the results of PSIL bend back testing as well as our ASTM ring flattening testing.

4. The PSIL Report indicates ESC as a "possible" root cause. The lack of certainty implies a lack of PSIL evidence and confidence of the results.

5. The FTIR results do not indicate a difference in composition of rinsates from the pressure/non-pressure sides of the gasket area.

6. Hexane rinsate analysis that suggests presence of traces of acrylates/phthalates/adipates data is not presented and does not compare to a solvent blank. This raises concern regarding the analysis.

7. Gasket pyrolysis does not indicate a difference between the used vs. new gasket material. This suggests no ESC agents were absorbed by the gasket. If ESC agents were present in the water being transported inside the piping, they would have likely been absorbed by the gasket and been detected in the analysis.

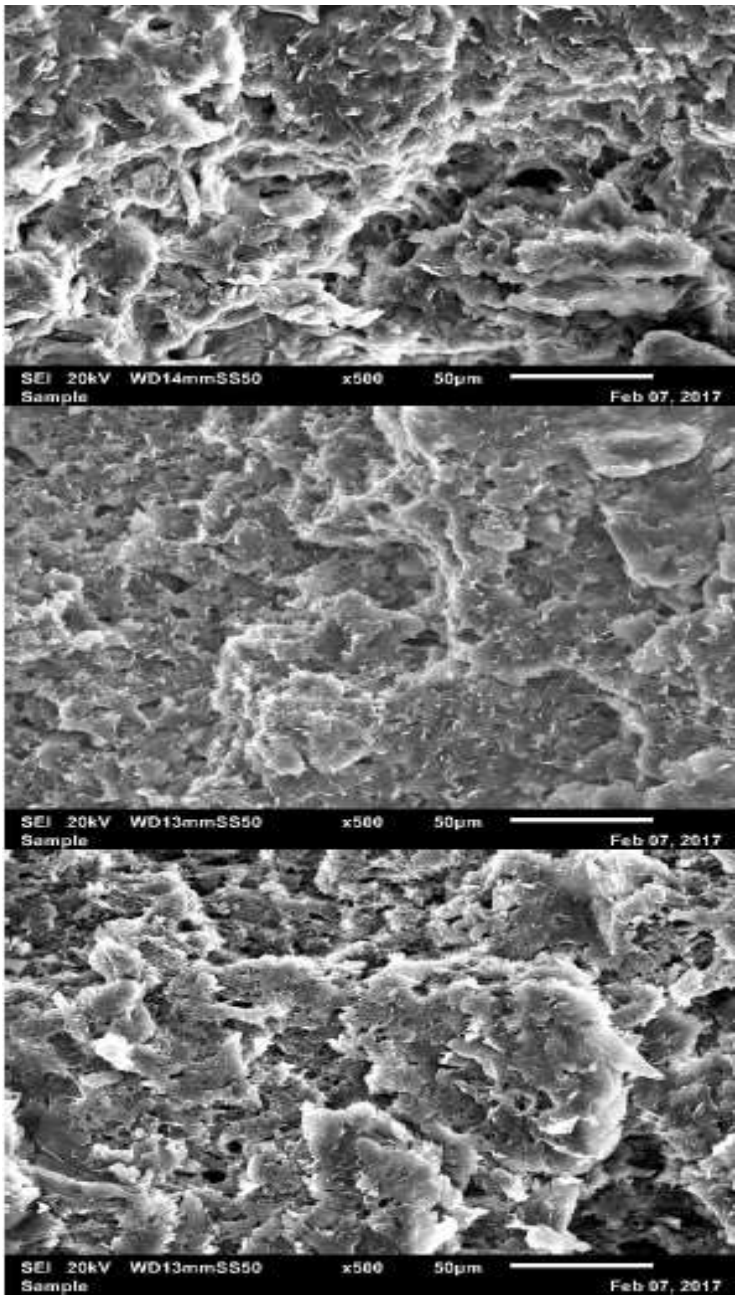


**Figure 1**. SEM images copied from PSIL Report (Figure 8) show ductile features consistent with creep failure, not ESC.

8. Our examination of a failed joint found bell deflection/annular gap (Figure 2). PSIL also noted joint deflection. This indicates undesirable flex action is occurred at the pipe joints. This finding is consistent with defective installation.

9. The "step cracking" noted in the PSIL Report is not uncommon in creep failure and is not strictly evidence of ESC failure in and of itself. No optical microscopy of the fracture surface

was offered to show evidence of characteristic thumbnail crack initiation common to ESC failure.

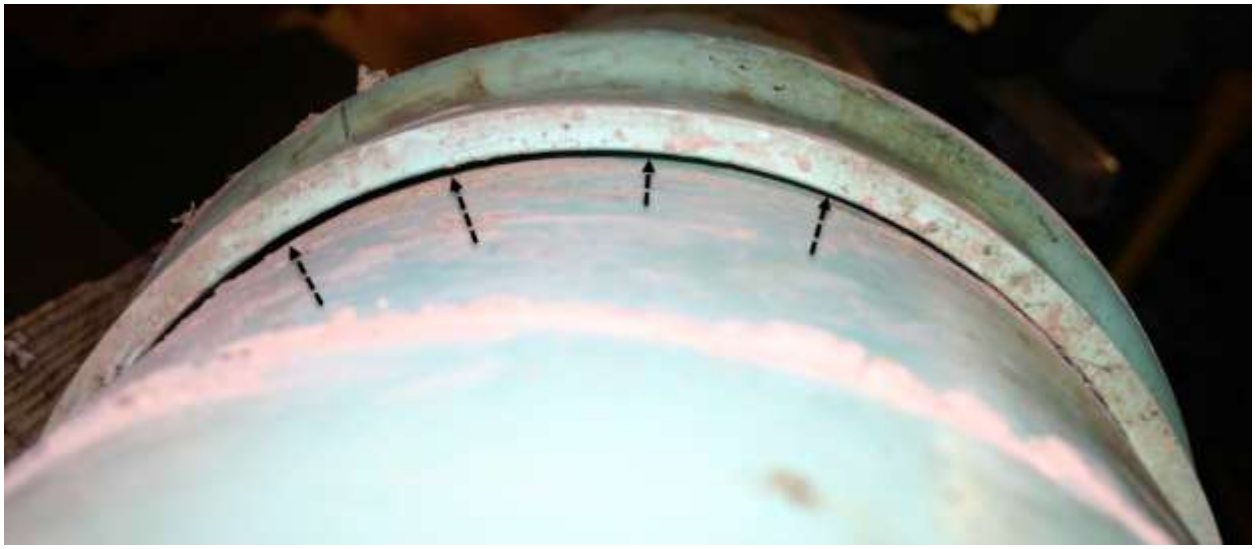

**Figure 2**. Photograph showing the annular gap between the spigot and the bell as indicated by arrows.

10. "Bend back" tests resulted in 2 of 3 samples failing, but the samples did not fail in the brittle mode. This is NOT supportive of ESC failure. The bend back test is not an ASTM test for PVC pipes. Instead, PVC ductility is measured by the ASTM ring flattening test. The results of our ASTM flattening test revealed high ductility supporting that the pipe had not absorbed incompatible chemicals.

11. The PSIL report contains the statement "evidence in hand does not fully support ESC as the primary cause of failure". Not only does the PSIL evidence not fully support ESC, we see no supporting evidence of ESC at all. In fact, the PSIL test results support that the bell failed by creep, not ESC.

12. Swelling of the gaskets is proposed by PSIL as an "as yet to be explained" means. No chemical materials were detected in the gasket that would account for this occurring.

13. Claims of chemical exposure were made but the testing was unable to provide evidence. Arguments for ESC by chemical exposure are made entirely by speculation. Both PSIL and our testing supports failure by creep not ESC.

14. Additional testing was done of the pipe and fracture surfaces by Materials Engineering Inc (MEI) and reported in documents B001010 and B001066. In those reports, a sample of PVC pipe was found to have trace amounts of hindered phenol antioxidant as well as trace amounts of hexanedioic acid bis(2-ethylhexyl) ester (estimated 3 ppm). Alkanes (waxes) and 1,4-benzenediamine, *N*-(1,3-dimethylbenxzyl)-*N*-phenyl (an antiozonate) were

detected. These trace chemicals are likely additives in the PVC formulation. Adipates and DEHP were observed in the solvent. The results indicate that solvents used to extract the chemicals contain the suspect ESC agents detected in the PSIL testing as blank analysis of extraction solvent was not indicated. Only trace amounts, below the level required to cause ESC, of potential ESC agents were mentioned in the B001010 report.

15. In the B001066 report, only a trace amount of dioctyladipate (less than 0.3 ppm) was detected. The long chain C26-aliphatic hydrocarbon, 9-Hexacosene, was observed at ~5 ppm as well as an antioxidant (likely additive to the PVC). Long chain aliphatic hydrocarbons are compatible with PVC and do not cause ESC.

16. In an attempt to deflect away from defective installation as the cause of stress which caused the creep failure of the bell joints, PSIL stated "*Regarding the joint assembly workmanship and alignment, the two samples were received in generally straight alignment, although some deflection was evident based upon annular gaps around the bell lip circumference. As noted prior, the spigots were appropriately belled, i.e. generally inserted to the manufacturer's recommended minimum insertion mark, i.e. just up to the first of the two manufacturer's marks. There was some amount of fine-grained debris in the joint area, both in the gap between the gasket sealing lobes as well as fore and aft of the gasket, including behind the gasket as previously discussed, with Sample E2 containing much more of this fine grained debris in comparison (see Figure 17). Note that the fine grained debris was most likely NOT present during insertion as no translational artifacts were noted within the debris filled areas*." We disagree with this statement. A misalignment condition present in the joints in the installed condition would have naturally been relieved upon removal of the joints from the trench in which they were constrained. PSIL noted debris in the joint on both sides of the sealing gasket. Common sense indicates that debris ahead of a sealing gasket would have been introduced when the spigot was slid into the bell.

**Overall Conclusions and Expert Opinions**

PSIL presented no evidence which deflects away from the conclusion that the bell joints failed by defective installation. PSIL was unable to find evidence to support the notion that the failure was caused by absorption of incompatible chemicals. Instead, the data generated by PSIL supports our conclusion that the failure mode was long term creep failure. Our finding of deflection and annular gap in the joint (also noted by PSIL) supports pipe alignment as the source of the stress that caused the creep failure of the bell joints.

SEM evidence of long term stress crazing (creep failure) and resulting microcracking with microductility and drawing of material is clearly present.

The ductility observed in the initiating microcrazing/microcracking defines the failure as long term stress cracking (creep failure) as opposed to ESC. Evidence does not exists that supports the presence of ESC agents since only trace chemicals were found, most of which are either present in the PVC formulation or else in the laboratory solvents used during the testing. Based upon our work, and the physical evidence of deflection and annular gap in the joints, indicate pipe misalignment during or after installation causing long term stress on the joint and subsequent failure.

Reference

1) https://www.highbeam.com/doc/1G1-438207399.html

**Appendix**

CV of Dr. Duane Priddy

Dr. Duane B. Priddy is the founder and CEO of Plastic Expert Group and Failure Labs. He has spent over 40 years in the Plastics Industry as a leading authority on plastic and composite part failure. He worked for Dow Plastics as one of their leading Principal Scientist. Dr. Priddy is a world renowned scientist and author as evidenced by his many awards including Dow's Lifetime Achievement Award. In 2001 he was awarded "Fellow" by the Polymeric Materials Division of the American Chemical Society. In 2008 he was awarded "Fellow" by the Society of Plastics Engineers for his pioneering work in the development of Plastic Science & Technology. He is a member of ASM International (a society of Material Scientists), the American Chemical Society Polymer Chemistry and Polymeric Materials Divisions, the International Association of Plumbing and Mechanical Officials, the National Association of Subrogation Professionals, the Society of Fire Protection Engineers, the Failure Analysis Division of the Society of Plastics Engineers, the Institute of Packaging Professionals, and the Society of Automotive Engineers. Dr. Priddy has provided expert services in over 180 litigations involving plastics and composites since 2003. He is one of the top experts in the world on the failure of PVC and CPVC piping products having analyzed thousands of pipes and fittings. Dr. Priddy has also been involved in failure analysis of hundreds of plastic and composite parts including bottles, tanks, latches, toys, medical devices, exercise equipment, automotive parts, pulleys, chairs, plastic food packages, plastic films, and stools. Dr. Priddy has served as an expert in over 150 litigations and has authored >100 scientific papers, >60 US Patents, a book entitled "Modern Styrenic Plastics", and several encyclopedia articles on chemicals and plastics.

**CONSULTANT AND EXPERT WITNESS ON CHEMICALS AND PLASTICS**

- Root cause analysis of plastic parts and devices
- Remediation of failing plastic piping systems

- Plastic piping products including ABS, HDPE, PVC, CPVC, PEX, PP, PVDC
- Additives for plastics including antioxidants and UV stabilizers
- Weatherability of plastics, films, and coatings
- Exercise equipment failure
- Design of plastic parts to meet the requirements of the application
- Fracture mechanics of plastic materials and composites
- Chemical resistance/degradation of plastics and elastomers
- Discoloration and loss of clarity of plastics
- Plastic part and package design and stress analysis
- Polymer blends and compounding
- Polyolefin based resins and applications
- Adhesives and coatings failure
- Additives for improved adhesion in polymer blends and composites
- Chemicals and Plastics R&D
- Monomer stabilization and polymerization
- Molding and extrusion of plastics including foams and films
- UV, thermal, and environmental degradation of chemicals and plastics
- Plastic flammability and plastic flame retardant formulations
- Migration of chemicals and additives from plastics
- Chemicals and plastics for medical use
- Composite and nanocomposite materials including carbon fiber composites
- Failure of fiber reinforced plastics (FRP) and composites
- Material Selection (choosing the right plastic for the application)
- Best practices for solvent cemented joints

**EDUCATION**

- Ph.D. Organic Chemistry - 1971 - Michigan State University
- BA Chemistry - 1966 - Olivet College, Olivet, MI

**MAIN ACCOMPLISHMENTS**

- > 60 Issued United States Patents
- >100 Publications including 5 encyclopedia articles and 8 book chapters
- Author/Editor of book “Modern Styrenic Polymers” Wiley 2003

**WORK EXPERIENCE**

- Over 30 years experience as a leading Research Scientist in Dow Chemical serving as Principal Scientist for Dow’s Polycarbonate and Styrenic Plastics Businesses.
- Led team of Dow Scientist to develop a fundamental understanding of the science of weathering of plastics.
- CEO of Plastic Expert Group and Failure Labs - 2003 to present

**ACADEMIC**

- Adjunct Professor at Michigan Technological University – 1988 - 1995
- Adjunct Professor at Central Michigan University – 1988 to present

**HONORS & AWARDS**

- Awarded "Fellow" of the Society of Plastics Engineers (SPE) 2008
- Awarded "Lifetime Achievement Award" by Dow Chemical – 2001
- Awarded "Fellow" National American Chemical Society (ACS) PMSE – 2001

**Litigation Experience Last 4 years**

| Matter | Description | Plntf | Dfns | Service | Year |
|---|---|---|---|---|---|
| Packaging Personified v Ice King | PE bag odor | x | | C | 2017 |
| Travelers v Subzero | PEX tubing failure | | x | C | 2017 |
| Coutant et al v PF Chang et al | Adhesive failure | | x | EO/D | 2017 |
| Lexington v Guttenberg | Plastic part failure | | x | C | 2017 |
| Salerno v EB Brands | Exercise ball failure | x | | C | 2017 |
| AMCO v Fire Engineering | CPVC pipe failure | | x | C | 2017 |
| Dwight Hartley v Rubbermaid | Plastic chair failure | x | | EO | 2017 |
| AT Films v Celanese | Polyolefin film manufacture | x | | EO | 2017 |
| Fabara v GoFit | Exercise ball failure | x | | EO/D | 2016 |
| Randy White v Swisher Hygiene | Bottle closure failure | x | | C | 2016 |
| Hanover Ins v Allied | CPVC fire sprinkler failure | x | | C | 2016 |
| United Clains v ICF | CPVC fire sprinkler failure | x | | C | 2016 |
| Pulte Homes v NIBCO | PEX pipe failure | x | | C/EO | 2016 |
| Patients v Ethicon | Transvaginal mesh | x | | EO/D | 2016 |
| Acosta v Bell Sports | Motorcycle Helmet failure | x | | C | 2016 |
| American Family Ins v Rick Plmbng | PEX tubing failure | | x | C | 2015 |
| Adams v Walmart & Cargill Meats | Food packaging failure | | x | C | 2015 |
| Lopez v Save Mart | Grocery Bag failure | | x | C | 2015 |
| Frazier v Dunkin Donuts | Coffee cup failure | | x | C | 2015 |
| Trump Hollywood v Allied et al | CPVC fire sprinkler failure | x | | EO | 2015 |
| Equistar v Westlake | Patent infringement | | x | C | 2015 |
| Tripp Harrison Gallery v Allied et al | CPVC fire sprinkler failure | x | | C | 2015 |
| 199 RiverOaks v Vistacom | CPVC fire sprinkler failure | | x | EO | 2015 |
| Jones v Heil | FRP part failure | | x | EO/D | 2015 |

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|---|---|---|---|---|---|
| Jones v Aultman Hospital | Catheter failure | | x | C | 2015 |
| Poshard v Thera-Band | Exercise ball failure | x | | C/EO | 2015 |
| Atlantic Automatic v IPEX | CPVC fire sprinkler failure | | x | EO | 2015 |
| Levitan v Ball Dynamics | Exercise ball failure | x | | C/EO | 2015 |
| CNH v Arlon | PVC sign failure | x | | C | 2015 |
| Washington Square HOA. v. Big-D | CPVC Piping System Remediation | | x | C | 2015 |
| Patients v AMS | Transvaginal mesh | x | | C/D | 2014 |
| PrePlastics v. Ashland | Plastic quality dispute | x | | C | 2014 |
| Lexington Ins v Browning Constr | CPVC fire sprinkler failure | x | | EO | 2014 |
| MMPA v Marshall Film | Bag failure | | x | C/EO | 2014 |
| Selby v Makray Manufacturing | Microwave Bowl Failure | x | | EO | 2014 |
| Forsyth II v Simplex Grinnel | CPVC fire sprinkler failure | x | | EO | 2014 |
| Durbin v Kennedy International | Stool failure | x | | EO | 2014 |
| Webber v Kennedy International | Stool failure | x | | EO | 2014 |
| Grand Dunes v Prestige | CPVC fire sprinkler failure | x | | EO | 2014 |
| Maitin v Publix | Grocery bag failure | x | | C | 2014 |
| Borman v Embark Fitness | Exercise ball failure | x | | EO | 2014 |
| Dowhaluk v Everlast | Exercise ball failure | x | | EO | 2014 |
| Cop v Bell Sports | Exercise ball failure | x | | EO | 2014 |
| Settlers Loop v Eco Existance | CPVC fire sprinkler failure | | x | C | 2014 |
| SubZero v. KX | Water filter failure | x | | C | 2014 |
| Buckley v Peg Perego | Toy breakage / personal injury | | x | C/EO | 2014 |
| Nealson v McDonalds/Pactiv | Injury caused by defective spoon | x | | EO | 2014 |
| Esplanade v Fifth & Continental | CPVC fire sprinkler system defects | x | | EO/CT | 2013 |
| LeFluer v Burger King & Dart | EPS foam Coffee Cup Failure | x | | EO | 2013 |
| Post Properties v FLSA | CPVC fire sprinkler failure | x | | C/EO | 2013 |
| Grove Construction v Furguson | PVC pipe failure | x | | EO | 2013 |
| Pure Ins v Olin | Hose failure | | x | C | 2013 |
| Rubitsky v BMW | Automotive composite part failure | x | | C/D | 2013 |
| Pedvin v Ossur | Knee brace failure | x | | C | 2013 |
| Schug v Bamboo Leaf | Chair failure | x | | C/EO | 2013 |

Key: C = Consultant / EO = expert opinion / D = deposition / CT = courtroom testimony

**Scientific Articles and Publications**

Duane Priddy, Rowland Hall, Dan Beaudoin**, Selecting the Best Remediation Option for Failing CPVC Piping Systems,** Society of Plastic Engineers 2016 ANTEC Proceedings

Duane Priddy and Tom Peeler, **Root Cause of Failure of an EPS Foam Coffee Cup,** Society of Plastic Engineers ANTEC 2014, Paper# 1838094.

Duane Priddy, **Forensic Analysis of CPVC Fire Sprinkler Piping,** Subrogator, Spring/Summer 2012, pp. 72 – 77.

Duane Priddy, **When CPVC Pipes and Fittings Fail in Hydronic Heating Systems**, Plastics Engineering, April 2012, pp. 4 – 9.

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Saczalski, Ken, West, Mark, and Duane Priddy, **Damage Analysis Technique for Evaluation of Plastic Seats in Handicapped Mobility Devices**, Proceedings of the SAMPE Tech 2011 Conference, Session on Design, Analysis, and Simulation II, Fort Worth, Texas October 17-20. Obtain a copy of this paper at http://plasticfailure.com/portfolio/failure-analysis-plastic-seat/ **.**

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Howell, B. A.; Powers, J. J.; Duane Priddy, **Thermal decomposition of cycloadducts of vinylnaphthalenes with electron-deficient dienophiles.** Center for Applications in Polymer Science, Central Michigan University, Mt. Pleasant, MI, USA. Journal of Thermal Analysis and Calorimetry (2006), 85(1), 141-143

Howell, B. A.; Cui, Y.; Duane Priddy, **Determination of residual levels of unsaturation in partially hydrogenated poly(2,3-diphenyl-1,3-butadiene) using thermogravimetry.** Journal of Thermal Analysis and Calorimetry (2004), 76(1), 313-322.

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Li, Irene Q.; Knauss, Daniel M.; Duane Priddy.; Howell, Bob A. **Synthesis and reactivity of functionalized alkoxyamine initiators for nitroxide-mediated radical polymerization of styrene.** Polymer International (2003), 52(5), 805-812.

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**Most Recent 50 US Patents**

| PAT. NO. | Title |
|---|---|
| 7,320,201 | Hollow plastic block assembly for wall construction |
| 6,573,349 | High molecular weight monovinylidene aromatic polymers with good processability |
| 6,503,992 | Phosphorous-containing monomers and flame retardant high impact monovinylidene aromatic polymer compositions derived therefrom |
| 6,214,945 | Process for producing high molecular weight styrenic polymers and polymodal compositions |
| 6,156,855 | Production of branched polymers |
| 6,084,044 | Catalyzed process for producing high molecular weight monovinylidene aromatic polymers |
| 5,990,255 | High molecular weight polysytrene production by vinyl acid catalyzed free radical polymerization |
| 5,962,605 | High molecular weight polystyrene production by vinyl acid catalyzed free radical polymerization |
| 5,959,033 | Polymers containing highly grafted rubbers |
| 5,948,874 | Acid catalyzed polymerization |
| 5,721,320 | In situ block copolymer formation during polymerization of a vinyl aromatic monomer |
| 5,677,388 | Difunctional living free radical polymerization initiators |
| 5,663,252 | Process for preparing a branched polymer from a vinyl aromatic monomer |
| 5,650,106 | Extruded foams having a monovinyl aromatic polymer with a broad molecular weight distribution |
| 5,627,248 | Difunctional living free radical polymerization initiators |
| 5,618,900 | Free radical polymerization |
| 5,473,031 | Branched polystyrene production by free radical bulk polymerization |
| 5,408,023 | Preparation of modified vinyl polymers |
| 5,347,055 | Oligomers of styrene as flegmatizers for organic peroxides |
| 5,194,658 | Process for making 2-amino-3-methyl-1-naphthalenecarbonitrile |

5,194,527 Preparation of ketone containing photodegradable polymers
5,187,249 Degradable B-alkoxy vinyl ketone resin composition
5,145,924 Free radical polymerization of styrene monomer
5,115,058 Bio- and photo-degradable resin composition
5,115,055 Hydroperoxide catalyzed free radical polymerization of vinyl aromatic monomers
5,087,738 Multifunctional cyclobutarene peroxide polymerization initiators
5,079,322 Multifunctional cyclobutarene peroxide polymerization initiators
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4,910,274 Preparation of monohydroxy-containing polymers
4,895,907 Polymerization process using bisquinone peroxide catalyst
4,859,748 Process for anionic polymerization in a continuous stirred tank reactor
4,812,530 Polyether-polycarbonate-polyether triblock copolymers
4,812,514 Polymer blends
4,806,599 Polyolefin/polycarbonate/polyolefin triblock copolymers
4,789,730 Preparation of polycarbonate having reduced cyclic carbonate oligomer content
4,725,654 Process for anionic polymerization
4,704,431 Blends of polypropylene and vinylaromatic/.alpha.-methylstyrene copolymers
4,647,632 Production of copolymers of .alpha.-methylstyrene
4,572,819 Apparatus for anionic polymerization wherein the molecular weight of the polymer is closely controlled
4,389,517 Hydrogenation of phenylacetylene prior to styrene polymerization
4,288,379 Hydrocarbon polyl gem-bis(t-alkylperoxy)alkanoates derived from .beta.-keto-acids
4,275,182 Process for the preparation of improved styrene acrylic acid copolymers
4,195,169 Devolatilizing polymers of styrene and acrylic or methacrylic acid
4,178,263 Organic peroxide compositions
4,131,728 Method for polymerizing olefinically unsaturated monomers employing a catalyst composition comprising (a) shock-sensitive organic peroxide and (b) an olefinic unsaturated non-homopolymerizable monomer
4,087,599 Preparation of a water-soluble polyvinylbenzyl quaternary ammonium halide
4,052,464 Process for the manufacture of di-t-butylperoxy ketals
4,029,685 Peroxy esters of pyromellitic acid