Plastics Institute of America, Inc.
A Non-Profit, Educational, and Research Organization

Secondary Reclamation of Plastics Waste

RESEARCH REPORT—PHASE I

PHASE I

Development of Techniques for Preparation and Formulation

**AUTO/APPLIANCE SHREDDER RESIDUE,
MIXED INDUSTRIAL WASTE,
CURBSIDE SEPARATED CONSUMER WASTE**

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A WORD ABOUT THE PLASTICS INSTITUTE OF AMERICA

While the Plastics Institute of America is officially designated a non-profit organization, it does try to generate reasonable "surplus" from its many efforts. Its basic purpose is to create sufficient revenues to support the diverse educational and research needs of the plastics industry.

To help develop the necessary financial resources, PIA relies heavily on member support through dues and other contributions. But the Institute also conducts intensive short courses at graduate level, publishes scientific theses, produces audio cassettes and organizes research conferences to add to these resources.

During the past 24 years more than 60 different courses were conducted and $3 million in research fellowships were sponsored. More than a dozen such fellowships are awarded annually to outstanding graduate students at leading universities.

There are a number of plastics societies and organizations serving the industry, but PIA is unique in devoting its efforts to education and research exclusively. The end result is a human resource development program that helps keep rising young professionals abreast of a rapidly growing and changing marketplace.

It is this investment in people and ideas that has enabled PIA to contribute to the progress of plastics in industry, government and academia.

ACKNOWLEDGEMENTS

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Michael J. Curry
Research Director
Plastics Institute of America

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EXECUTIVE SUMMARY

This report presents preliminary conclusions and recommendations as to the technical and economic feasibilities of recycling auto shredder plastic waste residues for use as plastics molding and extrusion materials.

The recycling of such manufacturing wastes has become more widespread over recent years because of the manifold increases in the cost of natural gas, the raw material from which most of the plastics in an automobile have been made.

This work on making the auto shredder residue technically and economically usable and feasible in molding or extrusion was carried out by graduate students in polymers under the direction of faculty members at five universities under the overall coordination of the Plastics Institute of America, a not-for-profit industry association housed at the Stevens Institute of Technology in Hoboken, New Jersey.

Initial work at Stevens involved exploratory experiments to define the composition, basic properties etc. of the shredder residue. This showed that the residue varied within a lot and between lots and contained more and different mixes of plastics as the model years of the cars being shredded increased. Additionally a considerable portion of the residue was such non-plastics as stones, paper, metals, fibers, etc. which should be removed for conventional injection molding and extrusion processes.

The residue in its fluffy state was examined for possible end uses at Lowell University. Initially it was compared with building materials such as particle boards (chip boards) which use waste wood chips in a thermoset polymer matrix hardened by curing. It was then shown that the auto shredder residue fluffs could be compression molded "as is" using bonding agents to yield a particle board substitute with marginal properties. The thermoset construction material approach was predicated on the residues at very low cost applications which often incorporate thermoset binders in a compression process. Later experiments using higher compression pressure conditions improved the properties to the point where it is felt such combinations might be usable in construction applications.

Work was then extended to thermoplastic binders which were again evaluated by compression molding of test pieces. These are also probably usable as low specification construction materials. The recipe involved two roll milling the "as is" residue and additives to masticate the mix followed by a 3000 psi pressure compression molding of test pieces. Compression molding was used to evaluate these thermoplastics instead of injection molding because of the time, equipment availability, smaller amount of material required, cost and scheduling advantages. Injection molding gave samples with higher properties than compression molding but compression molding was adequate for the screening work.

All the additives to make the auto shredder residue (ASR) fluff were commercially available and low to medium in price although considerably more costly than the residue itself, except for a very costly fluorinated polystyrene prepared for evaluation at the Polytechnic Institute of New York. These model compounds have high hydrogen bonding capabilities which it is believed would make them strong compatibilizers of the mixed plastics in the shredder residue. Initial evaluation of a small scale batch at Lowell showed that such model material gave the best properties of any binding agent. However when the synthesis of the fluorinated polystyrene was scaled up and the new material evaluated the original results were not duplicated. Although the properties were good, they were only a few times better than the other added agents. Reasons for the failure to reproduce earlier results were not found.

Coincident work at Stevens Institute on the flowability of the shredder residue, which is an important property for extrusion, showed that the ASR extrudates from the flow tester did not come to a constant flow indicating a probable decomposition or instability. Since at this time one of the senior investigators was aware of the technique of high loading of non-reactive fillers into good flow matrices, a series of studies were made using polyethylene-polypropylene mixes as the matrix and adding ASR as a filler up to 90% of the final composition. These materials were scaled up and were used in the full scale pilot trials of extrusion and injection moldings. The results of those trials are reported on in the Phase II report of this project.

Similar formulations using either polyethylene or polypropylene have been used in the Lowell compression molded evaluations. However, there is some evidence that the mixed additive behaves synergistically.

A completely different end use for the shredder residue was studied at Lehigh University where it was used to replace the aggregate in polymer concrete. Polymer concrete is a high performance cement-like material which is made by substituting mono and difunctional acrylic monomers for the cement in regular concrete. Its uses have been limited by its high cost in comparison to regular cement concrete, but it is used in some specialty uses. Therefore, ASR polymer concretes were made by substituting the auto shredder residue for the aggregate (stones and gravel) in the regular polymer concrete formulations. The products were easily made in the same machines at the same conditions as for polymer concrete. The material filled molds and cured well. Its compressive strength was in the concrete range. No further work was done with this material but the concept and data will be made available to potential users. It is a high-cost material and comparable to polymer concrete and will therefore have to find specialty uses, if any, because of that high price.

INTRODUCTION

The Plastics Institute of America (PIA) has been interested in "Plastics Recycling" since the mid-1970s. At that time the consensus was that the recycling of plastics from an energy and waste management standpoint was an issue that needed to be addressed. While exploring the role of the PIA in such recycling, Dr. Lincoln Hawkins, then the Research Director, participated in a recycling conference, ECO TECHNIC VI, presented by the National Association of Recycling Industries and other industry supporters in New York City in 1976.

This was followed by participation of Dr. Hawkins in an ERDA/CONRT (Energy Research and Development Administration) "Polymers and Energy Conservation Workshop" in 1977 in Washington, D.C. In 1980, ERDA's successor agency, the Department of Energy, funded the work. The research was carried out at the University of Texas at Austin, Case Western University, the Polytechnic Institute of New York, Pennsylvania State University and Carnegie-Mellon University. The results were published in February, 1980 in a Final Report entitled "Maximizing the Life Cycle of Plastics." This work led to more than five Master of Science and three Doctoral Theses, as well as a number of publications.

In 1981, The Department of Energy's Energy Conversion and Utilization Technologies (DOE/ECUT) Program began the funding of this present study on the Recycling of Beverage Bottles and Auto Shredder Residues. ISIS (Institute of Scrap Iron and Steel, Inc.), the industry organization of the Auto Shredders, joined in the support of the early work.

DOE/ECUT is primarily interested in secondary (use as a plastic in less demanding applications) and tertiary (recovery of chemicals and fuels) recovery of value of post-consumer plastic scrap. Primary recovery (reuse as a plastic in the same or similar application) seems to be well addressed by the private sector and quarternary recovery of energy content, (primarily by burning) is being developed by the private sector and the Energy from Municipal Waste Division of the DOE Office of Renewable Technology. The recovery of value from industrial captive or nuisance plastic scrap is also, in general, the province of the private sector. Secondary recovery was given initial funding by DOE/ECUT as it was deemed to be a "simpler" problem than tertiary recovery and, therefore, perhaps more likely to produce near-term results. Plastics from auto shredder residue were selected for study in secondary recovery as they are high-volume, relatively isolated (i.e. not mixed with other wastes such as in trash) waste streams.

DOE/ECUT plans to fund research on tertiary recovery in the future.

The Institute of Scrap Iron and Steel (ISIS) was interested in utilizing this waste rather than having to pay to have it trucked to landfills as is the present practice.

PIA subcontracted the work to Stevens Institute of Technology, the University of Lowell, Lehigh University, the University of Texas, Princeton Polymer Laboratories and the Polytechnic Institute of New York. The approaches to the research took into account the nature of the residues and the processes by which they are formed.

Auto Shredder Residue (ASR) is a fluffy material that remains from the shredding of junked cars and appliances after the removal of shredded metals. The metals are sold in the scrap metal market and the fluff is usually trucked to landfill sites. Presently there are approximately a million metric tons of the fluff generated yearly. About 50% (or one half million metric tons of the fluff) is a plastic fraction containing thermoplastics, thermosets, elastomers, fibers, etc., and is thus a complex mixture of incompatible polymers. The remaining 50% is dirt, stones, some smaller pieces of metal, etc. In addition, the fluff is not of constant composition because of the variability of the feed to the shredder. Since mixtures of incompatible polymers lead to lower product properties, it would be expected that the ASR would be a wide specification material suitable for less demanding end uses (secondary recovery). Further, since included metals can cause wear problems in some plastics processing equipment, as much of the metals as is economically feasible should be removed.

Therefore, research objectives were (1) to physically and chemically characterize the residue, (2) to determine the 'as is' properties, (3) to modify the residue with commercial or, if necessary, experimental additives in order to compatibilize the plastic components, (4) to evaluate the use of the residue in polymer concrete, a special and less demanding end use, (5) to determine how to process the residue into potentially useful materials, (6) to determine the economics of the processing, and (7) to identify commercially viable end uses.

The initial raw material supplied to the universities was obtained in 1980 and was called 1980 ASR. The material is dark colored and contains a wide range of different sized particles often unidentifiable as to origin. The term 1980 signifies that the residue was obtained from the shredder in 1980. The term "1980 residue" was used during the course of the work even though additional supplies of the residue were obtained from the shredder in the 1981 to 1985 period. The differentiation of these 1980-85 materials was based on lot numbers since all were called 1980 ASR. It is important to recognize that a 1980 residue should result on the average from the shredding of a ten year old 1970 car. Since the use of plastics in cars increased and the types of plastics changed rapidly during the 1970's, the so-called 1980 residue obtained in 1985 has a different plastic level as well as composition compared to the 1980 residue obtained in 1980.

Since in 1980 the PIA was in possession of data on the amount and kinds of plastics going into 1980 autos, (which would be shredder feed in 1990), it was able to make up a simulated "1990 residue" by adding the necessary amounts of ground up pieces of plastics to the 1980 residue to simulate a 1980 car's average plastic composition.

The research at each university is reported separately in this report. In some instances it was a part of the student's thesis, (e.g., Stevens Institute of Technology and Lehigh University). In other instances the work was only reported over a period of time in quarterly reports and the final reports were compiled and edited by Dr. M. J. Curry, the current Research Director of the PIA.

Following the initial separation and analysis of the 1980 ASR at Stevens Institute, Lowell University undertook the determination of the properties and the addition of various polymers and other additives to improve the property levels. Much of this work was necessarily based on knowledge of similar known systems.

At the same time, Lehigh University was able to proceed with the polymer concrete work since it was intended that the ASR be used essentially "as is." The experimental polymer concrete work concentrated on the acrylic and styrene polyester systems using the ASR as the aggregate.

The work at the Polytechnic Institute of New York involved the syntheses of compatibilizing agents and resulted in the preparation of a highly fluorinated styrenic polymer, which in initial tests at Lowell University showed the highest compatibilizing ability of any of the additives used; however, when the synthesis process for this compound was scaled up and the resultant product was tested at Lowell University, results were less encouraging.

Work at Stevens Institute, based on flow studies, lead to the selection of a specific polyethylene-polypropylene blend as the preferred additive to the ASR for commercial trials.

EVALUATION OF THE CONSTITUENTS AND THE POTENTIAL USES OF THE NON-METALLIC RESIDUE FROM AN AUTOMOBILE SHREDDER

REPORT BASED ON DATA OBTAINED

BY MS. HOA THI PHUNG DAO

AT

STEVENS INSTITUTE OF TECHNOLOGY

The work involved in this report, by Ms. Dao from the Stevens Institute of Technology, was carried out between 1979 and 1981 primarily under funding by the Plastics Institute of America and Institute of Scrap Iron and Steel. It forms a base for all the subsequent work on auto shredder residue (ASR) and was used by those who extended this work to the formulation, testing, processing and application stages. It is included for the sake of completeness. This report is an edited version of an M.S. thesis submitted by Ms. Dao in 1981.

EVALUATION OF THE CONSTITUENTS AND THE POTENTIAL
USES OF THE NON-METALLIC RESIDUE FROM
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ABSTRACT

That the metal fractions from retired automobiles is recycled is well known, but after the metal fractions are removed, a light fraction remains. This light fraction consists of plastics, rubbers, some metals, copper wire, glass, paper, cloth and small quantities of minor constituents. Currently this fraction is dumped or burned; thus, at the automobile shredder it has a negative value. With the current high price levels for plastic resins the question arises as to whether the plastics can be recovered and recycled. Adding impetus to this line of thought is the fact that today's automobiles contain much more plastic than those currently being retired. Tomorrow's automobiles will contain even higher percentages of plastics. The work contained in this thesis addresses the recycling of the light fraction.

Before separations could be attempted the constituents of the light fraction, which we will call Auto Shredder Residue (ASR), had to be identified. Samples of the fraction were obtained from an automobile shredder and manually separated into various distinct subfractions of which one was plastics. The second part of this work was the determination of the quantity of each constituent present, since this determined the uses which could be made of the light fraction. At this stage the glass and fractions of mineral particulates were deemed to be undesirable and were removed leaving a clean light fraction which was subjected to further separations. In concurrent experiments using a series of float tanks containing liquids of varying densities, the clean light fraction of ASR was separated into five subgroups. This gave a quick and repeatable technique to obtain fractions which were richer in plastics. There were now available a variety of separated and cleaned subfractions of the original light fraction. Attempts were then made to compression mold and extrude these fractions, as well as use them as filler for injection molded parts. These attempts were by and large unsuccessful. With a view to the future, fractions were then mixed which simulated the expected residues from today's automobiles. Similar processing attempts were made and, although more success was achieved, the results fell short of expectations. A final set of trials was made