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TECHNOLOGY ASSESSMENT OF AUTOMOTIVE APPLICATIONS OF METAL-PLASTIC LAMINATES

Volume I

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16. Abstract

An analysis is presented of the potential use of metal-plastic laminates in automotive structures based on the relative physical properties and costs of laminates to steel, and on the compatibility of the laminates with current automotive manufacturing practice. Laminate cost/weight and manufacturing analyses were performed on selected components from a passenger automobile and light duty truck. There are a number of small, non-visible, functional components currently made with steel sheet that would be likely candidates for laminate use.

The current commercial status of metal-plastic technology is reviewed, and the potential automotive use of laminates over the next decade is assessed. It is projected that laminates will not have a measurable impact on the fuel economy of U.S. production automobiles at least through 1990.

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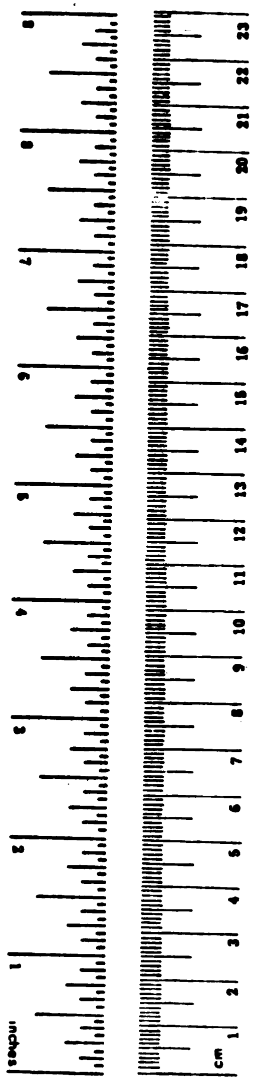
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

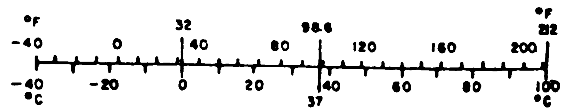
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This analysis was performed to assess the technology and the long term impact of metal-plastic laminates on automobiles for DOT/National Highway Traffic Safety Administration, Office of Passenger Vehicle Research.

The study was conducted under sub-contract to Corporate-Tech Planning, Inc., 275 Wyman Street, Waltham, MA, as part of Contract No. DOT-HS-9-02110, entitled "Review and Evaluation of Automobile Fuel Conservation Technologies". Two case study analyses were performed as part of this study by Pioneer Engineering and Manufacturing Company, 2500 E. Nine Mile Road, Warren, MI 48091. In these case studies, likely applications of metal-plastic laminates on two representative motor vehicles were identified, and the effect of metal-plastic laminate substitution on the cost and weight of a selected number of components was then analyzed.

The assistance and guidance of Mr. William Basham, Technical Monitor for NHTSA, and Mr.Theodore Taylor Jr., CTP Program Manager, in the execution and completion of this study are gratefully acknowledged. The help and support of Messrs. Norman Ludtke, Henry Kaminski, Jack Gilmore, and of Ivan Shadko of Pioneer in the development of the case study analyses, added substantially to the content of this report.

During the course of this study, discussions and exchanges of views were maintained with many members of the technical community that had an interest in the various facets of the technology of metal-plastic laminates, as listed in Appendix A. The help and cooperation of all concerned is also gratefully acknowledged.

Robert Kaiser
Argos Associates, Inc.
Principal Investigator

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LIST OF SYMBOLS

A_1	Calculated Part Area
AA	Aluminum Alloy
AK	Aluminum Killed
B	Buckling Resistance
C	Crippling Resistance
^oC	Degree Centigrade
D	Denting Resistance
DOT	Department of Transportation
E	Tensile Modulus = Flexure Modulus
E^*	Effective Flexure Modulus
E_a^*	Apparent Flexural Modulus
E_{s1}	In-plane Stiffness of a Laminate
ECC	Electrolytic Chrome Coated
F	Flexural Strength
F^x	Vibration Frequency
^oF	Degree Fahrenheit
G	Shear Modulus
GPa	Giga-Pascal
I	Moment of Inertia
J	Joule
HD	High Density
Kcal	Kilo-calorie
Kg	Kilogram
L	Local Buckling Resistance
LD	Low Density
LDR	Limiting Draw Ratio

LIST OF SYMBOLS (Cont.)

M	Bending Moment Resistance
M^F	Bending Moment Resistance in Fatigue
MPa	Mega-Pascal
N	Newton
$\bar{N}$	Shear Deflection Factor
NARI	National Association for Recycling Industries
NHTSA	National Highway Traffic Safety Administration
P	Applied Vertical (end) Load
PBT	Polybutylene Terephthalate
PET	Polyethylene Terephalate
S	Stiffness
S^b	Bending Stiffness
S^t	Torsional Stiffness
SAE	Society of Automotive Engineers
Tg	Melting Temperature (amorphous)
T_m	Melting Temperature (Crystalline)
T_{max}	Maximum Air Temperature in Paint Bake oven
T_{min}	Minimum Temperature
V	Shear Force
W	Weight per Unit Area
W_p	Part Weight
Y	Stress Yield Factor
b	breadth
cm	centimeter
db	decibel

h	dent depth
hr	hour
in.	inch
k_B, k_s	beam loading constants
lb	Pound
m	meter
mm	millimeter
s_c	shear stress in core
t	thickness
y	total deflection
α	Core Volume Ratio
$(\dot{\varepsilon})$	strain rate factor
ν	Poisson's Ratio
ρ	density
σ	ultimate tensile strength
σ^F	fatigue strength
σ_C	compressive stress
σ_{sl}	inplane strength
σ_y	tensile yield strength
σ_{yaf}	apparent value of yield strength of face sheet
σ_c^*	tensile strength of core at laminate yield point
σ_f^*	tensile strength of face sheet of laminate yield point
L	refers to laminate property (subscript)
c	refers to core property (subscript)
f	refers to facing property (subscript)

LIST OF SYMBOLS (Cont.)

sub-
scripts

n	new material
o	original material
s	refers to steel property

super-
scripts

n	geometrical constant
o	Degree

EXECUTIVE SUMMARY

The purpose of this study was to assess the long term impact of metal-plastic laminates on automobile structures. The metal-plastic sandwich laminates that are the focus of the present study are thin sandwich structures that have external metal facings, such as steel or aluminum, bonded to a thermoplastic core such as polypropylene, polyethylene or nylon 6-6. Laminates of interest are typically less than 2.5 mm (0.100 in) thick, and have core volume ratios, i.e. relative plastic content on a volume basis, of about 50 to 80 percent. These laminates are designed to replace sheet steel in applications where rigidity is the design constraining criterion. Laminates would not be weight effective substitutes for steel in applications which require in-plane strength.

Potential benefits that would be derived from using metal-plastic laminates instead of sheet steel in automotive structures include:

a) a potential direct weight reduction of 50 to 70 percent over steel in stiffness limited applications.

b) capability of being cold formed with standard sheet metal stamping presses.

c) improved acoustical properties as compared to sheet metal, which could lead to possible additional weight reduction through the elimination of some of the sound deadening materials now used in automobiles.

There are a number of technical issues and problems that have to be resolved before laminates would be likely to be used in production automobiles. These include issues that are generic to laminates as a class such as:

a) specific design methods and criteria: the design limiting criterion for a laminate structure may not be the same as for a sheet steel structure, and thus the weight savings that may result may be lower than anticipated.

b) joining and assembly: the conventional welding techniques now used by the automobile industry do not appear to be suited to the joining of metal-plastic laminates. Of the various possible joining methods that could be considered, namely adhesive bonding, specialized welding procedures, or mechanical fastening, structural adhesive bonding would be the most satisfactory. This method is not commonly used by the industry at the present.

c) mechanical repair of fabricating damage, especially to appearance parts.

d) compatibility with lead-alloy seam fillers

e) crashworthiness characteristics of laminate structures

f) scrappage and reclamation of laminate parts and offal.

Composition specific issues include fabrication limitations on components such as:

a) room temperature formability characteristics of aluminum faced laminates

b) width limitations on steel faced laminates imposed by the commercial availability of face sheet material

c) stability in paint-bake ovens of laminates with low melting polyolefin cores.

Or the environmental resistance of the laminates; such as

a) corrosion resistance of steel face sheets

b) low temperature impact properties of polypropylene cores

c) stability of the specific metal-plastic bonding agents.

A preliminary manufacturing analysis of the projected costs of metal-plastic laminates was performed which examined the costs associated with various raw materials and alternate laminating processes. With automotive sheet steel (0.8 mm thick) prices at $3.20 per square meter, and functionally equivalent aluminum sheet available at $7.60 per square meter, competing metal-plastic laminates must be priced at about $5.00 per square meter to be viable options. These costs constraints require that laminates be made on a semi-continuous or continuous basis, rather than by the batch technique now used by many suppliers. Semi-continuous or continuous lamination would not be new technology. Many existing coil coating facilities could be used to make laminates on a semi-continuous, as has been demonstrated already by one firm. These cost constraints favor steel over aluminum faced laminates even though the latter have a greater weight reduction potential. They also favor the use of low cost polymers for the core. Laminates become more competitive as the thickness of the steel sheet replaced increases.

Pioneer Engineering and Manufacturing Co. Inc. used the results of the tear-down analyses of a 1978 Omni passenger automobile and a 1979/1980 Ford F-150 light truck to identify those components that could potentially be made from metal-plastic laminates if all design and manufacturing problems were solved. From this list a more detailed manufacturing analysis was performed for selected components to arrive at estimates of weight savings and cost penalties that would accrue from the substitution of a suitable metal-plastic laminate for the base line sheet metal. The weight savings premium ranged from $0.13/lb to $1.80/lb for the twelve parts that were analyzed in detail. The weight savings penalty is a strong function of the manufacturing scrap rate. For a number of the parts examined, such as a grille bracket or a front seat frame, replacement of sheet steel with a metal-plastic laminate would result in a cost penalty of significantly less than $0.50/lb. For these components, both the feasibility and economics of metal-laminate substitution are favorable.

An assessment of the current commercial status of metal-plastic laminates was obtained from discussions with potential suppliers and potential automotive users of metal-plastic laminates. The general consensus is that metal-plastic laminates will be used by the automobile industry but that significant further investigation is required to qualify them for any production use. Potential users in the automobile industry are looking for improved performance, better reproducibility and lower costs than they have been able to obtain to date. There is also concern about the limited availability of these materials. The material suppliers, who have borne most of the cost of the development to date, are looking for more favorable signals from the automotive industry before making major new investments in the technology. Providing improved lower cost materials for nearer term use is, however, feasible because such materials could be made with only minor-modifications of existing coil coating lines.

While it is possible to consider initial production use of laminates by 1985, extensive automotive use of laminates is at least a decade away. As a result it is projected that laminates will not have a measurable impact on the fuel economy of U.S. production automobiles prior to 1991.

1.0 INTRODUCTION AND SUMMARY

1.1 BACKGROUND

Metal-plastic sandwich laminates have become the subject of growing interest within the automotive industry as possible alternatives to conventional aluminum and steel sheeting now used to fabricate automotive components. These laminates have skins of thin metal sheets, typically aluminum or steel, bonded to a thermoplastic core, such as polyethylene, polypropylene or nylon, as shown in Figure 1-1. Because of their high stiffness to weight ratio, use of these laminates could result in components that would weigh no more, and possibly less, than comparable components made from aluminum sheet. Because these laminates offer the promise of being significantly less expensive than aluminum, components made from laminates should cost less than aluminum components. Another advantage proclaimed for laminates is that they can be formed into shapes by conventional sheet metal fabrication processes, such as stamping. Laminate parts could be formed with existing equipment, so that a component manufacturer would not be required to make significant capital investments in new equipment and tooling to use the laminates. Assembly of laminate parts could be achieved by adhesive bonding or mechanical fastening, two techniques with which the automotive industry is familiar. Because of their metal surfaces, it should be possible to finish and paint the laminates in the same manner as sheet steel, and obtain traditional "Class A" finishes in appearance parts.

With the attributes of potential weight reduction, compatibility with many current automotive manufacturing equipment and methods, and low cost penalties, metal-plastic laminates could become a major tool for weight reduction and improved fuel economy in future production passenger and non-passenger automobiles, and their introduction into the automotive industry could be fairly rapid.

The purpose of this report is to provide the Office of Passenger Vehicle Research of the National Highway Traffic Safety Administration (NHTSA) with the results of an independent assessment of the various technological and economic factors that will influence the use of metal-plastic sandwich laminates by the automotive industry, and the impact the laminates may have on automobiles during the coming decade.

1.2 METHODOLOGY

Within the context of the automotive industry, metal-plastic sandwich laminate technology is an emerging one, even though the use of laminate sandwich structures is not novel, and is well established, for example, within the aerospace and building

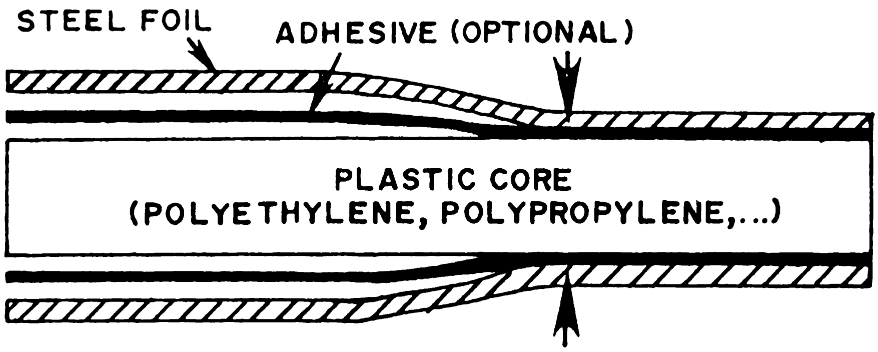

FIGURE 1-1. CONSTRUCTION OF A TYPICAL LAMINATE

construction industries. While there is a significant body of literature on composite laminates, there is relatively little published information available on laminates designed specifically for automotive applications and on their performance in automotive use. In order to arrive at an assessment of the current status of automotive applications of metal-plastic laminates, major emphasis was placed on identifying the companies and organizations that have active development programs in the area, or would otherwise have a stake or be affected by the technology, and arranging interviews with key technical and management personnel.

A list of the organizations visited during the course of the study is presented in Table 1-1. A list of the principal individual contacts made as a result of these visits, or through correspondence and telephone conversations, is presented as Appendix A. The exchange of information and viewpoints that resulted from these visits form the web of this assessment. This web was further supported by data gleaned from the technical literature in related fields and by independent analysis. While there was extensive contact between researchers in the field, developers and potential users of laminates, and the author, the views presented in this report are the author's, and these may not necessarily be in agreement with those of others currently active in the field.

1.3 SCOPE OF WORK

The following specific topics were addressed during the course of the study:

a. Discussion of material properties and weight savings potential of metal-plastic laminates currently being considered for automotive use.

b. Discussion of the suitability of metal-plastic laminates as far as their being able to meet other automotive design criteria.

c. Review of constraints imposed by automotive component manufacturing practice on the potential use and required properties of metal-plastic laminates.

d. Assessment of the repairability, scrappage and recycling of metal-plastic laminates.

e. Identification and analysis of the cost elements of metal-plastic laminates, including raw materials costs and lamination costs, to project the user price of laminates as a function of type and scale of production.

f. Identification of likely applications of metal plastic

TABLE 1-1

ORGANIZATIONS VISITED DURING THE COURSE OF THE STUDY

NAME OF ORGANIZATION LOCATION	PRINCIPAL CONTACT TITLE	DESCRIPTION
Amicon Corporation Lexington, MA	Dr. Justin C. Bolger Vice President	Adhesive Manufacturer
Arco Polymers Inc. Philadelphia, PA	Mr. Joseph D.DiCicco Project Manager, Commercial and Venture Development	Polymer Manufacturer
Arvin Industries, Inc. Arvinyl Division Columbus, IN	Mr. Harold R. Fisher Vice President Engineering	Coil Coater
Bethlehem Steel Corp. Bethlehem, PA	Mr. Howard M. Jones Manager, Capital Budgeting	Steel Producer
The Budd Company Ft. Washington, PA	Mr. Herbert A. Jahnle Manager Advanced Materials	Component Manufacturer
Consolidated Aluminum Corp. St. Louis, MO	Ms. Carla A. Lane Marketing Manager ALUCOBOND Division	Aluminum Manufacturer Laminate Manufacturer
Dow Chemical USA Midland, MI	Mr. Robert L. Hotchkiss Associate Scientist	Polymer Manufacturer
Carl Dunmon & Assocs. St. Louis, MO	Mr. Carl Dunmon President	Laminate Parts Fabricato
Ford Motor Company Dearborn, MI	Mr. Normal H. Jewell Principal Engineer Vehicles Material Eng.	Automotive Manufacturer
General Motors Corp. Research Laboratories Warren, MI	Dr. William K. Miller Senior Engineer Metallurgy Dept.	Automotive Manufacturer
Hercules Inc. Wilmington, DE	Dr. Allan D. Craig Manager Market Development	Polymer Manufacturer

Table 1-1 (Cont.)

ORGANIZATIONS VISITED DURING THE COURSE OF THE STUDY

NAME OF ORGANIZATION LOCATION	PRINCIPAL CONTACT TITLE	DESCRIPTION
Illinois Tool Works, Inc. Elgin, IL	Mr. E. Grant Swick Manager Venture Group	Supplier of Automotive Adhesive Bonding Systems
Inland Steel Company East Chicago, IN	Mr. Bernard S. Levy Product Consultant	Steel Producer
Marathon Electric Vehicles, Inc. Montreal, PQ, Canada	Mr. W. Howard Candlish President	Manufacturer of Specialty Vehicles
Mitsui & Co. (USA Inc. New York, NY	Mr. Ken Taguchi Plastics Dept.	U.S. Agent for Mitsui Petrochemicals, Ltd.-Polymer Supplier
Monsanto Plastics & Resins Co. St. Louis, MO	Dr. Lawrence W. McKenna Technology Manager	Polymer Supplier
NARI New York, NY	Mr. Howard Ness Technical Vice Pres.	Trade Association for the Recycling Industry
National Steel Corp. Weirton, WV	Dr. Glen Bush Division Chief Product Development	Steel Producer
Pre Finish Metals Inc. Elk Grove Village, IL	Dr. Howard H. Levine Manager Research Laboratory	Coil Coater
T. Sendzimir, Inc. Waterbury, CN	Mr. Michael Sendzimir President	Rolling Mill Designers
Siemon Company Watertown, CN	Mr. Karl H. Pohl Division Manager	Fabricator of Communications Equipment
SG&H, Inc. Cambridge, MA	Mr. Richard Chambers Senior Associate	Consulting Engineers
Stelco Inc. Hamilton, Ontario, Can.	Mr. Stanley Rocys Design Engineer	Steel Producer
United States Steel Corp. Pittsburgh, PA	Mr. Daniel Kobasa Coordinator Commercial Development Tin Mill Products	Steel Producer

laminates in automotive vehicles. This part of the study was performed by Pioneer Engineering and Manufacturing Company, Inc.

The results of the tear down analyses of a 1978 Omni passenger automobile and a 1979/1980 Ford F-150 light truck recently performed by Pioneer for NHTSA were used to identify those components that could potentially be made from metal-plastic laminates if all design and manufacturing problems were solved. From this wish list, a selected number of specific components were identified as low risk candidates where a metal-plastic laminate could be substituted for either sheet steel or sheet aluminum, and that the resulting metal-plastic laminate component could be designed, fabricated and integrated into an automotive structure, with low technical risk within the framework of current automotive manufacturing practice. A more detailed manufacturing analysis was performed for each of these selected components to arrive at estimates of the weight savings and cost penalties that would accrue from the substitution of a suitable metal-plastic laminate for the baseline sheet metal.

g. Discussion of the current status of metal-plastic laminate technology. Organizations that were identified as having an on-going activity in metal-plastic laminates during the course of the program are discussed in terms of their technological and commercial interests in the technology, to arrive at an assessment of the current status of the technology.

h. Development of upperbound estimates of the projected applications and use of metal-plastic laminates by the automobile industry over the next ten years, and the resulting demand for laminates and laminate manufacturing facilities.

i. Listing of the major research and development programs that will be required in order for metal-plastic laminates to achieve the levels projected above.

1-4 PRINCIPAL FINDINGS

The metal-plastic sandwich laminates that are the focus of the present study are thin sandwich structures that have external metal facings bonded to a thermoplastic core. The laminates of interest are typically less than 2.5 mm (0.100 in) thick. The metal facing materials being considered are principally aluminum killed (AK) low carbon steel, electrolytic chrome coated steel, and aluminum alloys. The design of the laminate establishes the thickness of these facings, which will typically range from 0.13 mm (0.006 in) to 0.25 mm (0.010 in), and are typical gauges for sheet metal now used by the can industry. The polymer cores being considered are principally polyolefins: polypropylene, polyethylene, or their copolymers, because of cost considerations (though one developer, Monsanto Company, is promoting the use of nylon 6-6, a more costly material, because of its improved performance characteristics). A third material that is sometimes required is an adhesive which bonds the polymer to the face sheets. In some systems, the polymer and/or the face sheets are treated in such a manner as to render the polymer self-adhering to the face sheets, so that a separately applied adhesive is not required. Laminates of interest typically have core volume ratios, i.e. relative plastic content on a volume basis, of about 50 to 80 percent.

The general characteristic of the laminates of interest is that these materials are designed primarily to replace sheet steel in applications where rigidity is the design constraining criterion. The basic principal of sandwich laminate construction is much the same as that of an I-beam, in that as much of the high density, high modulus material is placed as far away from the center of bending or neutral axis of the structure as possible. The facings act in concert to form an efficient internal stress couple counteracting the externally imposed bending moment. The core resists the shear stresses set up by the external loads and stabilizes the face sheets against wrinkling or buckling. Sandwich construction is a well established method of obtaining lightweight rigid structures, long used in the aerospace and building construction industries. The metal-thermoplastic laminates of interest differ from classic sandwich structures in that they are much thinner, and are capable of being cold formed into a desired shape <u>after</u> lamination.

The concept of post-formable metal-plastic laminates is about 20 years old. The technology did not develop principally because of lack of commercial interest, except for specialized applications such as architectural paneling. These initial uses of laminates were promoted by Mitsui Petrochemicals Ltd. in Japan, and Alusuisse in Europe. Recently, Consolidated Aluminum Corp., an Alusuisse subsidiary, introduced these architectural laminates in the U.S. Interest on the part of the U.S. automobile manufacturers in metal-plastic laminates developed only in the past two to three years because of the potential weight savings that could be achieved by replacing sheet metal with metal plastic laminate on automotive vehicles. Sheet metal use on a typical automobile and light truck is summarized in Tables 1-2 and 1-3. For both vehicles, the weight of sheet metal is approximately 23 percent of the vehicle curb weight.

1.4.1 Principal Benefits Claimed for Metal Plastic Laminates

<u>Weight Reduction</u>: Depending upon the geometry of the component and the specific composition of the laminate, replacement of sheet steel with a metal-plastic laminate of equivalent flexural stiffness can result in a direct weight reduction of 50 to 70 percent. For example, replacing sheet steel with a steel faced laminate with a 60 percent core volume ratio of equal stiffness could result in a weight reduction of about 50 percent. This laminate would only be about 10 percent thicker in gauge

TABLE 1-2

SHEET METAL COMPONENTS ON 1978 OMNI SEDAN

THAT COULD POTENTIALLY BE FABRICATED FROM METAL-PLASTIC LAMINATES

GENERAL APPLICATION	SHEET METAL AREA FT^2/CAR	STEEL SHEET METAL WEIGHT LB/CAR
EXTERNAL APPEARANCE PARTS	126	170
OTHER BODY PANELS	135	194
SEAT FRAMES	28	46
MISCELLANEOUS BODY PARTS	13	18
CHASSIS AND ENGINE APPLICATIONS	30	47
TOTAL ON-BOARD VEHICLE	332	475
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VEHICLE CURB WEIGHT		2,106

TABLE 1-3

SHEET METAL COMPONENTS ON 1980 FORD F-150 PICK-UP TRUCK THAT COULD POTENTIALLY BE FABRICATED FROM METAL-PLASTIC LAMINATES

GENERAL APPLICATION	SHEET METAL AREA FT^2/TRUCK	STEEL SHEET METAL WEIGHT LB/TRUCK
EXTERNAL APPEARANCE PARTS	250	399
OTHER BODY PANELS	166	239
SEAT FRAMES	18	33
MISCELLANEOUS BODY PARTS	31	69
CHASSIS AND ENGINE APPLICATIONS	65	98
TOTAL ON-BOARD VEHICLE	530	838
VEHICLE CURB WEIGHT		3,687

than the steel being replaced. If an aluminum faced laminate were considered, the weight reduction potential would be higher, from 55 percent to 70 percent depending on component geometry. Because of the low modulus of the aluminum facings relative to steel, this laminate would be 60 to 100 percent thicker than the sheet steel being replaced. These weight savings can be constrained by the need to meet other structural requirements, particularly in-plane stresses. In applications where such stresses exist, the weight savings potential is severely constrained, unless the facing materials have significantly higher tensile properties than the steel being replaced.

Formability: One of the principal advantages claimed for metal-plastic laminates is that components can be formed from laminate sheet by the same methods and equipment currently used to make the equivalent sheet steel components. The forming characteristics of laminates, however, are not quite the same as those of steel, and will vary with the properties and thickness of the face sheet, the total laminate thickness, and to a secondary degree, with the characteristics of the core. In general, it appears that metal-plastic laminates are intermediate in forming characteristics to AK cold rolled steel sheet, the current standard of the automobile industry, and automotive aluminum alloys. The forming characteristics of a laminate are principally established by the forming characteristics of the face sheets, but are superior to those of the unsupported face sheets. Blanking, trimming and springback characteristics of laminates are similar to those of steel. Laminates differ from steel in having a greater tendency to wrinkle under deep draws than steel sheet because it is difficult to support both the inner and outer skins during a forming operation.

One of the great advantages in focusing on steel faced laminates with less than a seventy percent core volume ratio is that these laminates are only ten to twenty percent thicker than a steel sheet of equal stiffness. As a result, the stamping dies that would be used to make such a laminate would be very similar to those now used to form the equivalent steel part. In some instances, where it is desired to make test parts from laminate stock, existing production dies might be used without modifications for these trial runs. Steel faced laminates with much higher core volume ratios, and aluminum faced laminates, will be significantly thicker than a steel sheet of equal stiffness. This can present an obstacle to the fabrication of test parts on existing tooling. The large gap thickness required to fabricate components from such laminates makes it unlikely that a die designed to stamp a steel part, could be used with these laminates without significant modification.

Whereas steel faced laminates can be formed at ambient, it has been observed that optimum forming of aluminum faced laminates, principally aluminum-nylon laminates, occurred at temperatures of 150°F to 225°F (66°C to 107°C).

Acoustic Characteristics: The metal plastic laminates of interest have better sound damping characteristics than sheet steel. This property could result in further possible weight reduction through the elimination of sound deadening materials. This characteristic of the laminates was not examined in any detail because of huge variations that appear to exist with the composition and geometry of the laminates that would be considered. Furthermore, laminates specifically designed for their sound damping properties were not included within the scope of the present study. These laminates consist of two fairly thick face sheets bonded by a fairly thin visco-elastic core, and do not offer any significant direct weight savings over steel.

1.4.2 General Issues Generic to All Metal-Plastic Laminates

The technical issues and problems discussed in this section apply to all laminates, irrespective of their composition. In addition to these issues, there are technical problems that apply only to specific laminates on the basis of their composition. These latter problems will be discussed in the next section.

Joining and Assembly: Joining and fastening of laminate parts to each other, or other materials, are complicated by the heterogeneity of the metal-plastic laminates. The effectiveness of attachment to one side of a laminate is limited by the strength of the skin and the skin-polymer bond. Attachment to both sides is costly and may not always be feasible. Of the various possible methods of joining that can be considered, namely adhesive bonding, welding, or mechanical fastening, structural adhesive bonding appears to be the most satisfactory method of joining metal-plastic laminate components. The major drawbacks are the time and temperature needed for cure which would require the use of jigging or other short term tacking methods. Conventional welding techniques that are the current method of joining sheet metal parts in the automobile industry do not appear suited to joining metal-plastic laminates. However, specialized welding methods that have been developed and used with pre-coated steels should be applicable in particular situations, especially with laminates that have relatively thick face sheets, i.e. greater than 0.6 mm (0.025 in) thick. The potential for creep of the polymer core under perpendicular loads to the laminate, and the resulting torque loss, severely limit the use of mechanical fastening as a method of attachment to applications where the applied stresses are small.

A consequential issue is that attachment points where loads are concentrated (such as hinges) will undoubtedly have to be reinforced in some manner. This will result in additional costs and lowered weight reduction.

Mechanical Repair of Fabricating Damage: While rigid quality control standards can minimize the presence of dents, dings, scratches and burrs, such defects will never be completely eliminated under high volume production condutions. In addition, joints between major body parts must be masked. Metal-plastic laminates are not compatible with current finishing practice. The filing and grinding methods now used to obtain smooth surfaces would remove a significant fraction, or possibly all, of the external skin, thereby greatly weakening the laminate. The lead solders now used to fill indentations and joints between steel body panels will cause local melting of any of the polymer cores being considered and are likely to result in local distortion. Changes in finishing practice are required if metal-plastic laminates are ever to be used in appearance parts. Such changes may not be easy to incorporate in an assembly line environment.

Crashworthiness of Metal-Plastic Laminates: At present, there is little information on the behavior of metal-plastic laminate components in a crash situation. Some preliminary crushing impact tests performed at the Budd Technical Center indicate that metal-plastic laminates do not appear to offer any significant cost or weight advantage over sheet steel in terms of their crashworthiness.

Stability Under Thermal Gradients: Significant thermally induced stresses may occur when a laminate is subjected to a severe temperature gradient across its thickness because of the thermal insulating properties of the core. In this case, there will be a differential expansion of one face sheet with respect to the other. This will cause "bowing" of simply supported panels, or induce significant bending and shear stresses in restrained panels. This problem could arise if metal-plastic laminates were used in certain under the hood applications, such as valve covers. Further data are still required to scope out this potential problem area.

Scrappage and Reclamation of Laminate Parts: Metal-plastic laminate scrap will have a finite scrap value, but this value will be less than the value now obtained for sheet metal scrap. This is because mixed materials, as a rule, have less value than a homogeneous material, and because of the low bulk density such a scrap would have, which makes it expensive to process and ship per unit weight of contained material, especially per unit weight of contained material. Of the three conceptual options for materials reclamation from metal-plastic laminate offal,--namely granulation of the laminate to reclaim a metal filled molding powder, separation of the metal skins from the polymer core with subsequent re-use of each material, and reclamation of the laminate for its scrap metal content--the last approach appears to be the most feasible. Difficulties which may result with this approach, other than for the low metal content per unit volume, would derive from the decomposition of the polymer core in the smelting furnace into particulates and noxious fumes, thereby increasing the duty requirements of environmental control systems. The extent to which this may occur will depend on the particular characteristics of the polymer present in the core, especially in terms of pyrolysis.

Whether or not metal-plastic laminates would be recycled will ultimately depend on their acceptability by smelters and furnace operators. Because scrap steel has a lower value than scrap aluminum, any factors which may constrain the reclamation of metal-plastic laminate scrap will have greater impact on steel faced laminates than aluminum faced laminates.

1.4.3 Composition Specific Issues Relating to Metal-Plastic Laminates.

Denting Resistance: Denting resistance can be a weight limiting constraint for laminates with very ductile steel face sheets (with a T-1 temper for example) and a core that does not contribute to the tensile properties of the laminate, such as polypropylene. This constraint is of lesser importance for aluminum faced laminates, in general, or for steel faced laminates of higher temper face sheets (which may not be as formable) or with a nylon core.

Dimensional Constraints: There are width limitations on the thin gauge sheets that would be used as laminate skins. In thickness of 0.2 mm (0.008 in) or less, steel sheet is available in widths of up to approximately 1 m (39 in), and aluminum alloys are available in widths of up to 1.2 m (50 in). Since facilities exist that would allow laminates to be made in widths of up to 1.8 m (72 in), the commercial availability of the sheet metal establishes the maximum width in which laminates could be made. This limits the automotive use of laminates to applications for which the minimum blank dimension is less than the maximum available width of the laminate. This constraint prevents laminates from being considered in applications such as the side panel of a van, for example.

The current width-thickness limitations on sheet metals are based on commercial demand rather than technical feasibility. The principal use of steel sheets less than 0.30 mm (0.012 in) thick is the food container industry which does not require wide stock. Another limitation on sheet width in these gauges is the width of the tinning lines through which most of the steel produced in these gauges must pass. Based on discussions with rolling mill suppliers and producers of tin mill products, sheets up to about 48 in. (1.2 m) wide in the gauges of interest could be produced on existing equipment, with some development effort, but without requiring major capital outlays. The availability of laminate sheets 1.2 m wide would be sufficient for many identified applications.

Producing sheet metal in widths greater than 1.2 m in gauges of less than 0.25 mm would require modification of existing wide sheet rolling lines. The required capital investments would vary significantly with the approach taken.

Stability in Paint-Bake Ovens: Problems have been encountered in the painting of formed metal-plastic laminate component parts because of severe mechanical distortion of these parts as a result of passage through the paint bake ovens. Any laminate part has to be able to survive half hour exposure to temperatures of either 400°F (204°C) or 350°F (176°C) depending on whether or not an electrocoat prime is used, which is characteristically applied to most of the components of the body-in-white. Distortion of laminate parts is primarily a function of the melting temperature of the polymer relative to the operating temperature of the paint bake over. Differential thermal expansion of the core relative to the skins of the laminate may be a secondary factor.

According to preliminary tests performed at Ford Motor Company, none of the metal-plastic laminates examined survived passage through the electrocoat bake oven, with only aluminum-nylon laminate surviving the spray prime bake. These results are not unexpected, except for the failure of the aluminum-nylon laminate under electrocoat bake conditions, given the thermal properties of nylon 6-6, and contradictory results on the stability of aluminum/nylon 6-6 laminate obtained by the supplier of the laminate (Monsanto Corp.).

Automotive painting practice is currently undergoing review and may be significantly modified in the near future because of increasing costs of energy and the need to meet more stringent environmental constraints. Within the constraints of costs and finish quality, the automobile manufacturers, and their paint suppliers are trying to develop primers and finishes that will cure at temperatures that are lower by about 50°F to 100°F (28°C to 56°C) than current practice. For the critical electrocoat bake oven, it is doubtful that oven air temperature will be less than 300°F (150°C). Spray prime bake ovens could be operating at air temperatures of 275°F (135°C) or less. This would allow one to project that polyolefin core laminates could be candidates, one day, for all parts except those that are electrocoated. For the latter, a laminate with a high melting nylon or polyester core would be required. For polyolefin cored laminates to be used for components that are now electrocoated, electrocoating practice would have to be discontinued, and the sheet metal would have to be primed before lamination and forming. This is unlikely to occur.

Durability and Environmental Stability of Laminates: Metal-plastic laminates must survive as integral structures over the lifetime of a vehicle in the aggressive service environment that exposed automotive components are subjected to. This implies that the metal face sheets, the polymer core, and the metal-plastic bond must not deteriorate, corrode or otherwise be altered so as to impair the functional characteristics of any components made from laminate.

As far as the face skins are concerned, the major issue is corrosion, particularly for steel faced laminates. The corrosion of the face skins is of greater concern with a laminate than the corrosion of a homogeneous sheet because a given absolute level of penetration will result in signficantly greater proportional loss in mechanical properties in the case of the laminate. If integrity of both skins is required, the useful life of a laminate may be less than 25 percent of the life of sheet metal of equal composition as the skins. If integrity of only one face sheet is required, a laminate may be superior to a metal sheet because the polymer core acts as a corrosion barrier. Corrosion will vary significantly with the composition of the skins. Materials options which would provide better corrosion resistance than AK steel, but which would also add to the costs, include ECC steel, zincro-metal coated steel, galvanized steel, aluminized steel, aluminum alloys, and stainless steel.

In terms of polymer stability, the major required characteristic is that the polymer remains functional over the total temperature range which a laminate can be subjected to. Polyethylene is limited to use temperatures of less than 75°C (167°F), polypropylene to use temperatures of less than about 115°C (240°F), and nylon 6-6 to use temperatures of less than about 200°C (390°F). With the exception of polypropylene, these polymers all have good mechanical and impact properties at low temperatures. Impact additives have been found to improve the low temperature properties of polypropylene.

Peel strength has been used as a measure of the stability of the core-skin bond, with limited aging, weathering and environmental exposure data obtained for some of the laminates. The most extensive data base has been obtained for thicker, aluminum faced laminates developed for architectural purposes, and for which no appreciable loss of bond strength has been noted as a result of weather conditions. Similar results were obtained with aluminum-nylon laminates. In comparison to the information reported in the literature for aluminum faced laminates, the data were minimal for steel faced laminates. Only verbal information from laminate developers was obtained on the aging characteristics of the steel-polymer bond. Results that have been obtained indicate that ECC steel faced laminates have survived standard 1000 hr salt spray tests. The paucity of information on the peel strength of mild steel faced laminates is disconcerting, especially when one considers that rust formation at the skin/core bond line could result in delamination. Further examination of this area is required.

1.4.4 Cost of Metal-Plastic Laminates

An analysis of the projected costs of metal-plastic laminates was performed in which the cost of the laminate to a user was considered to consist of two major elements: a) the costs of contained materials in a laminate, and b) the costs and profits associated with converting the metal and plastic raw materials into a laminate sheet. The cost of the contained materials is equal to the sum of the cost of the face sheets, the cost of the polymer core, and the cost of the adhesive if one is required. The costs of the raw materials can be established with accuracy since most of the materials involved are standard items of commerce. In some instances, assumptions had to be made with regards to the cost of the polymer used. The costs of converting these raw materials into laminates are not well established. These will depend significantly on the assumed laminating process and the scale of operation. To arrive at such cost estimates, it was necessary to perform a preliminary manufacturing and cost analysis for various alternate lamination processes, including two approaches to batch lamination on platen presses, continuous lamination with roll presses at two levels of operation, and semi-continuous lamination on existing coil coating equipment. Projected costs and capacity as a function of the assumed mode of operation are given in Table 1-4. As can be seen from this Table, laminating costs associated with batch lamination are significantly higher than those engendered by continuous lamination. Most of the metal-plastic laminates being developed for automotive use are currently being made in a batch mode on platen presses because of ease and expediency. The resulting costs and production rates preclude the use of laminates made in this manner from ever being used on production vehicles. In terms of any significant production use by the automobile industry, laminates will have to be made on a continuous basis because of improved economics, improved consistency and quality of product, and improved product form. With a continuous lamination plant, the metal-plastic laminate would be available in coils, which the automotive industry is used to handling, rather than in sheets of limited dimensions.

Continuous lamination is an established technology, and there are at least three continuous metal-plastic lamination plants in operation in various countries at the present time. It was estimated that a facility for the continuous manufacture of metal-plastic laminate would require an investment of about \$2 million for a 10^6 m^2/yr plant, and about \$18 million for a 17 x 10^6 m^2/yr plant. These production levels are based on 6,000 hr per year operation. The projected laminating cost of \$1.35/m^2 (\$0.125/ft^2) would be representative of conditions for a mature industry, and is the lowest projected value that can be assigned to laminating costs above the cost of contained materials.

Before suppliers invest in such facilities, however, demonstrated markets will have to exist. The classic supply-demand dichotomy that often plagues the introduction of any new material may be circumvented in the case of metal-plastic laminates because these materials could be manufactured on existing coil coating equipment for about \$2.50/m^2 (\$0.23/ft^2) above the cost of contained materials on a toll basis. At this laminating cost,

TABLE 1-4. ESTIMATED COST OF LAMINATE FABRICATION AS A FUNCTION OF PROCESS AND PRODUCTION LEVEL (EXCLUSIVE OF COST OF CONTAINED MATERIALS)

PROCESS	BATCH OPERATION MULTI-PLATEN PRESS	BATCH OPERATION SEQUENTIAL PRESSES	CONTINUOUS ROLL PRESS	CONTINUOUS HIGH VOLUME	SEMI-CONTINUOUS (TOLL BASIS)
Estimated Capital Investment in Physical Plant, $\$10^6$	0.85	1.35	1.6	18	existing facilities
Laminate Output, 10^3 m^2/yr	60 - 180	350 - 1050	1000 - 3000	17,000	8,000
		COST CONTRIBUTION, $\$/m^2$ of Laminate			
Sandwich Lamination	14.50 -6.61	3.60 - 1.70	2.12 - 0.88	0.85	1.80
Polymer Sheet Extrusion	0.20	0.20	0.20	included in above	0.20
Material Losses, Handling, Shipping, etc.*	0.50	0.50	0.50	0.50	0.50
TOTAL	15.20 - 7.30	4.30 - 2.40	2.82 - 1.58	1.35	2.50

* Nominal value used for calculations. Estimate varies from about $\$0.40/m^2$ to $\$1.00/m^2$ depending on specific composition of laminate.

laminates could be viable materials for a number of automotive applications. The coil coating industry's function is to apply a variety of organic finishes and coatings to sheet metal to provide decorative or corrosion resistant finishes. These same facilities can be used to apply a polymer film to a metal sheet. By performing this equation sequentially with two sheets of metal, it is possible to form a metal-plastic-metal sandwich, as has been demonstrated by Pre-Finish Metals Inc. of Elkgrove Village, Illinois. This company has already prepared a 4,000 lb (1800 kg) coil of adhesively bonded steel-poly propylene-steel laminate in this manner.

The projected costs of metal-plastic laminates to the user are considered to be the sum of the cost of contained materials and of conversion costs and profit. The projected costs of various metal-plastic laminates that are likely to be used by the automobile industry are presented in Tables 1-5 and 1-6. The costs are presented on a per unit area basis rather than on a per unit weight basis for ease of comparison. Table 1-5 presents the weight and costs per unit area of various laminates and of 5052 aluminum alloy sheet that would be functionally equivalent to an 0.8 mm thick steel sheet in terms of stiffness for a curved panel, i.e. stiffness varies as the product of the flexure modulus and thickness squared. Table 1-6 presents comparable data for laminates that would be used to replace 1.6 mm thick steel sheet.

For the nearer term, total costs are projected on the basis of semi-continuous lamination in a coil coating facility at a conversion cost of $\$2.50/m^2$ for the thinner laminates, and of $\$3.00/m^2$ for the thicker laminates. These differences arise from variations in the amount of material that has to be handled and scrapped. Differences in scrappage and handling costs between the various material combinations, and the cost of the adhesive (if required), were neglected in these calculations as being within the accuracy of the estimate. For the longer term, the costs were based on laminating charges of $\$1.35/m^2$ for the thinner materials, and $\$1.85/m^2$ for the thicker materials. These costs assume continuous, high volume lamination. Costs of contained materials are based on standard list prices for the various materials, except for the cost of polypropylene co-polymer and the lower value of the cost of nylon 6-6. Based on discussions with the developer (Hercules, Inc.), a purchase price of \$0.70/lb (\$1.54/kg) was assumed for the polypropylene copolymer. Since Monsanto Corporation projects that the cost of the nylon 6-6 contained in a laminate would be less than the current list price of nylon molding powder, a range of costs is given for nylon 6-6 cored laminates in Tables 1-5 and 1-6. The lower end of the range is based on the current value of \$0.90/lb (\$1.98/kg) for off-specification grade nylon 6-6 on the secondary market, the upper end of the range is based on the current list price of nylon 6-6 molding powder of \$1.34/lb (\$2.95/kg).

TABLE 1-5. WEIGHT AND COST PER UNIT AREA OF SHEET MATERIALS OF INTEREST OF COMPARABLE[a] PERFORMANCE TO STANDARD AUTO SHEET STEEL (0.80 MM THICK)

MATERIAL	THICKNESS mm	CORE VOLUME RATIO a	WEIGHT/AREA kg/m^2	COST OF CONTAINED MATERIALS $\$/m^2$	PROJECTED COST OF PRODUCT NEARER TERM[b] $\$/m^2$	PROJECTED COST OF PRODUCT LONGER TERM[c] $\$/m^2$
Steel - Polyolefin	1.0	0.6	3.682	2.66	5.16	4.01
Steel - Polypropylene Copolymer	1.0	0.6	3.682	2.99	5.49	4.34
Steel - Filled Polypropylene	1.0	0.6	3.936	2.62	5.12	3.97
Steel - Nylon 6-6	1.0	0.6	3.828	3.18-3.77	5.68-6.27	4.53-5.12
Aluminum - Polyolefin	1.9	0.8	2.407	3.77	6.27	5.12
Aluminum - Nylon 6-6	1.5	0.6	2.694	5.72-6.72	8.22-9.22	7.07-8.07
Aluminum (5052)	1.35	-	3.649	7.60	7.60	
Cold Rolled AK Steel	0.80	-	6.280	3.20	3.20	
Cold Rolled AK Steel	0.89	-	6.987	3.56	3.56	

Notes

a) Aluminum and aluminum faced laminates are functionally equivalent (Et^2= constant) to 0.80 mm thick sheet steel. Steel faced laminates are minimum gauge products contemplated by suppliers. These laminates are functionally equivalent to 0.89 mm steel sheet on the basis chosen.

b) Based on semi-continuous manufacture on a toll basis in an existing coil coating facility @ $\$2.50/m^2$

c) Based on a large scale (17 million square meter/year) dedicated facility @ $\$1.35/m^2$

TABLE 1-6

WEIGHT AND COST PER UNIT AREA OF SHEET MATERIALS OF INTEREST

OF COMPARABLE [a] PERFORMANCE TO HEAVY GAUGE SHEET STEEL (1.6 MM THICK)

MATERIAL	THICKNESS mm	CORE VOLUME RATIO α	WEIGHT/AREA kg/m^2	COST OF CONTAINED MATERIALS $\$/m^2$	PROJECTED COST OF PRODUCT NEARER TERM[b] $\$/m^2$	LONGER TERM[c] $\$/m^2$
STEEL - POLYOLEFIN	1.8	0.6	6.622	4.35	7.35	6.20
STEEL - POLYPROPYLENE COPOLYMER	1.8	0.6	6.622	4.91	7.91	6.76
STEEL - FILLED POLYPROPYLENE	1.8	0.6	7.079	4.28	7.28	6.13
STEEL - NYLON 6-6	1.8	0.6	6.884	5.96-7.03	8.96-10.03	7.81-8.88
ALUMINUM (5052)	2.7	-	7.298	14.95	14.95	
COLD ROLLED AK STEEL	1.6		12.560	6.41	6.41	

Notes

a) Substitution materials are functionally equivalent (Et^2= Constant) to 1.6 mm thick steel

b) Based on semi-continuous manufacture on a toll basis in an existing coil coating facility @ $3.00/m^2

c) Based on a large scale (17 million square meter/year) dedicated facility @ $1.85/m^2

In the nearer term, all the laminates considered as replacement for 0.8 mm steel sheet, are intermediate in price to steel and 5052 aluminum alloy, except for aluminum-nylon laminate. In the longer term, all the laminates, including nylon 6-6/aluminum laminate based on the lower cost estimate for nylon 6-6, would be less expensive than 5052 aluminum alloy. The laminates would however still be more expensive than 0.8 mm steel. In this case, the lowest cost differential would be $0.77/m^2, or 24 percent of the cost of steel, for steel-filled polypropylene-steel laminate. The cost differential for the laminates would have to be justified in terms of the weight savings that would result because of their lower weight per unit area.

Laminates designed to replace thicker 1.6 mm steel sheet are proportionately less expensive than laminates designed to replace 0.8 mm steel sheet. In the nearer term, steel-polyolefin laminates could be only 14 percent more expensive than 1.6 mm steel sheet, and in the longer term, these laminates would be less expensive than 1.6 mm steel. These lower costs for the thicker laminates follow because the cost of contained materials are less than the cost of the steel, and the conversion costs are essentially independent of thickness of the laminate, so that the laminates become more competitive as the thickness of the steel sheet replaced increases.

1.4.5 Component Substitution Analysis

An analysis was conducted by Pioneer Engineering and Manufacturing Company to select suitable candidate parts for laminate application, to determine their weight and cost, and compare the results with that of the current components. Previous vehicle teardown studies on a Chrysler Omni passenger car and a Ford F-150 pickup truck provided an available source of parts and data for review and selection of candidates. A physical review of all Omni and F-150 parts was made to select the candidates for the cost-weight study. Use of the laminates was based on the properties presented in Table 1-7, and the constraints listed in Table 1-8. The cost of laminates assumed were representative of a developing industry that was not yet mature, but had advanced beyond batch manufacturing. Upper bound values of raw material costs were also assumed.

Table 1-9 presents a list of representative parts rejected as candidates for substitution in this study because of various technical constraints. Tables 1-10 and 1-11 present the results of the cost/weight analysis performed for five (5) Omni parts and seven (7) F-150 parts that were selected as candidates for laminate use. These parts are all internal to the vehicle (i.e. nonappearance parts) with relatively low levels of loading. None of the restraints to the use of laminates that have been identified apply to these parts. These parts appear to be of the type that the industry would select for initial laminate application.

For each of these parts, the sheet metal design was reviewed, and changed, where necessary to accommodate the particularities of the laminate. Once the components were redesigned, the variable costs were developed by establishing each manufacturing operation required to produce the finished part or assembly. The associated labor/burden costs for each operation are developed and summed along with material costs to arrive at the final cost. These data do not include fixed costs which are normally included in total manufacturing costs.

A review of the COST/LB SAVED column in Tables 1-10 and 1-11 indicates that there is a relatively large difference among the various components of the cost penalty for weight savings as a result of laminate substitution. The principal reasons for these differences are:

- o Laminate materials can be formed into most part shapes with the same fabrication processes used to form sheet metal parts. For these parts, fabrication costs in laminate will be equal to, or nearly equal to, the fabrication costs of the part in sheet metal. The differences in variable manufacturing costs will be mainly a function of the difference in the costs of raw materials.

- o The costs of raw materials increases with the offal rate since they are based on the cost of the purchased material blank. As a result, the cost penalty for weight savings increases with the offal rate, and if the offal rate is high, the penalty for weight savings will be high. Since the unit cost of laminate is higher than the unit cost of sheet steel, high offal rates magnify the cost differences between the laminate and the original sheet metal.

- o Replacing thin aluminum sheet with an aluminum-nylon-aluminum laminate results in a fairly high cost penalty for weight savings. The difference in density between aluminum and aluminum-nylon laminate is fairly small, so that the amount of weight saved is also small. Secondly, since the laminates that are being substituted are very thin, the cost is dominated by the lamination costs, so that the unit laminate costs are high.

The general consensus of the automotive industry is that weight savings has a current value of about $0.50/lb ($0.90/kg), and may be three times as much by the end of the decade. For a number of the F-150 parts listed in Table 1-11, replacement of sheet steel with a metal-plastic laminate would result in a cost penalty of significantly less than $0.50/lb. These components include the grille brackets, the torque converter access plate, the floor pan access hole cover, and the front seat frame. For these components, both the feasibility and the economics of metal-laminate substitution are favorable. These components would be prime candidates for initial production use of laminates. The cost penalty for the other three components

TABLE 1-7 PROPERTIES OF LAMINATES USED FOR DESIGN PURPOSES

DESIGNATION	S-P-S	S-P-S	S-P-S	S-P-S	S-N-S	S-N-S	A-N-A	A-N-A
FACE SHEET MATERIAL	Steel	Steel	Steel	Steel	Steel	Steel	Aluminum	Aluminu
CORE	(PP)	(PP)	(PP)	(PP)	Nylon 6-6	Nylon 6-6	Nylon 6-6	Nylon 6
LAMINATE THICKNESS, IN.	0.040	0.068	0.150	0.325	0.040	0.068	0.035	0.030
FACE SHEET THICKNESS, IN.	.008	0.0135	0.030	0.062	.008	0.0135	0.007	0.006
VOLUME PERCENT CORE	60	60	60	60	60	60	60	60
WEIGHT PER UNIT AREA, LBS./FT.^{2}	0.77	1.31	2.88	6.26	0.80	1.40	0.33	0.24
FLEXURAL STIFFNESS, 10^6 psi	21	21	21	21	21	21	7.8	7.8
FLEXURAL STRENGTH, 10^3 psi	33							
FLEXURAL FATIGUE STRENGTH, 10^3 psi	20	20	20	19				
TENSILE MODULUS, 10^6 psi	12	12	12	12	12	12	4	4
TENSILE STRENGTH, 10^3 psi	24	21	21	19				
TENSILE FATIGUE STRENGTH, 10^3 psi	14	14	14	14				
FORMING LIMIT DIAGRAM-FLD_o, PERCENT	33	30	36	47				
LIMITING DRAW RATIO	1.8	1.8	2.0	1.9				
DENT DEPTH @ 20 in-lb, in.	.073	.044	.021	.008				
STRESS RELAXATION CHARACTERISTICS PERCENT RETAINED AFTER SEVEN WEEKS (15.6 psi INITIAL)								
ROOM TEMP.	65	63	60	54				
150°F	63	60	58	41				
240°F	43	38	31	26				
MAXIMUM EXPOSURE TEMPERATURE IN FABRICATION, °F	270	270	270	270	440	440	440	440
MAXIMUM USE TEMPERATURE, °F	200	200	200	200	400	400	440	440
MAXIMUM AVAILABLE SHEET WIDTH								
CURRENT AVAILABILITY, in.	36	36	72	72	36	36	50	50
FUTURE AVAILABILITY, in.	48-72	48-72	72	72	48-72	48-72	60	60
COST OF LAMINATE								
$/M^2	5.01	6.70	11.11	20.99	6.17	8.92	6.23	4.69
$/ft^2	0.47	0.62	1.03	1.35	0.57	0.83	0.58	0.44
$/lb	0.61	0.48	0.36	0.31	0.72	0.59	1.74	1.82

TABLE 1-8

STUDY ASSUMPTIONS CONSTRAINING THE CHOICE OF AUTOMOTIVE COMPONENTS AS LIKELY CANDIDATES FOR NEAR-TERM USE OF METAL-PLASTIC LAMINATES

* CONSIDERED THE USE OF METAL-PLASTIC LAMINATES IN STIFFNESS LIMITED PARTS THAT WERE NOT:

- APPEARANCE PARTS
- SAFETY CRITICAL PARTS
- PARTS SUBJECTED TO SEVERE TEMPERATURE GRADIENTS
- PARTS WHERE MECHANICAL FASTENING IS CRITICAL

* STEEL FACED LAMINATES WITH 60 PERCENT CORE VOLUME RATIO ARE USED EXCEPT WHERE USE OF MINIMUM WEIGHT STEEL FACED LAMINATE (WITH 0.2 MM SKINS) WOULD RESULT IN WEIGHT GAIN, OR WHERE CORROSION CONSTRAINTS WOULD BE SEVERE. IN THESE INSTANCES, ALUMINUM FACED LAMINATES WERE CONSIDERED

* POLYPROPYLENE CORE LAMINATES ARE USED EXCEPT WHEN THE COMPONENT IS EXPOSED TO A FABRICATION TEMPERATURE OF 150^{o}C (300^{o}F) OR MORE OR AN IN-USE TEMPERATURE OF 120^{o}C (250^{o}F) OR MORE. IN THESE INSTANCES, NYLON CORE LAMINATES WOULD BE USED

* THE PRICE OF THE LAMINATE IS ASSUMED TO BE EQUAL TO THE COST OF CONTAINED MATERIALS PLUS \$0.20/FT^2 (\$2.16/M^2)

MANUFACTURING RESTRAINTS
ON LAMINATE MATERIALS

	Re-Strike	Extruded Bearing Surface	Serrated Fittings	Mechanical Fasteners-Rivets, Bolts, Sheet Metal, Screws, etc.	Material Elongation (Stretch)	Metal Finish	Warping (Paint Cycle)	Spring Stop	Bearing Surface	Hot Upset & Mech. Staking
Door Latch Mech.	X	X		X	X			X	X	X
Hood-Outer						X	X			
Window Regulator	X	X	X	X					X	
Master Cyl. Cover	X				X					
Cowl					X		X			
Fender-Outer				X		X	X			
Fender-Inner				X	X					

TABLE 1-10

LAMINATE STUDY CANDIDATE PART COST/WEIGHT ANALYSIS - 1978 OMNI

PART DESCRIPTION	CURRENT PART: FIN. WGT. (lb.)	CURRENT PART: MATL. (1)	CURRENT PART: BLANK COST ($)	CURRENT PART: BLANK WGT. (lb.)	CURRENT PART: VARI. PIECE COST ($)	USAGE	LAMINATE SUBSTITUTE: FIN. WGT. (lb.)	LAMINATE SUBSTITUTE: MATL. (2)	LAMINATE SUBSTITUTE: BLANK COST ($)	LAMINATE SUBSTITUTE: BLANK WGT. (lb.)	LAMINATE SUBSTITUTE: VARI. PIECE COST ($)	PER VEHICLE: Δ WT # -	PER VEHICLE: Δ $ +	PER VEHICLE: COST/LB SAVED
OMNI PARTS														
RR SEAT BACK PNL	15.22	.035 CRS	4.46	17.44	7.80	1	9.07	.040 SPS	8.54	14.00	12.83	6.15	5.03	.82
HOOD PANEL INNER	15.25	.035 CRS	7.63	30.5	10.43	1	7.74	.040 SNS	11.15	15.48	13.92	7.51	3.49	.46
LIFTGATE INNER	5.20	.033 CRS	6.45	25.8	10.50	1	2.9	.040 SNS	10.37	14.4	14.63	2.3	4.13	1.80
DOOR PANEL INNER-FT	6.94	.030 CRS	2.89	11.56	6.86	2	4.23	.040 SNS	5.14	7.05	9.14	5.42	4.56	.84
DOOR PANEL INNER-RR	4.46	.030 CRS	2.25	8.92	6.22	2	2.73	.040 SNS	3.92	5.45	7.92	3.46	3.40	.98

(1) CRS = Cold Rolled Steel
(2) SPS = Steel Polypropylene Steel
SNS = Steel Nylon Steel

TABLE 1-11

LAMINATE STUDY CANDIDATE PART COST/WEIGHT ANALYSIS - 1980 F-150 PICK-UP TRUCK.

	CURRENT PART						LAMINATE SUBSTITUTE					PER VEHICLE	
PART DESCRIPTION	FIN. WGT. (lb.)	MATL. (1)	BLANK COST ($)	BLANK WGT. (lb.)	VARI. PIECE COST ($)	USAGE	FIN. WGT. (lb.)	MATL. (2)	BLANK COST ($)	BLANK WGT. (lb.)	VARI. PIECE COST ($)	Δ WT # - / Δ $ +	COST/LB SAVED
F-150 PARTS													
ENG. AIR CLNR.	3.28	.030 AL / .030 CRS	2.34 / .44	2.34 / 1.74	See Laminate	1	2.40	.035 ANA / .040 SNS	3.20 / .82	1.84 / 1.13	Δ +1.24	.88 / 1.24	1.41
GRILLE BRKT-RT&LT	1.07	.032 CRS	.34	1.34	See Laminate	1	.62	.040 SPS	.48	.78	Δ +.14	.45 / .14	.31
TORQUE CONV ACCESS PLT	.46	.037 CRS	.13	.51	See Laminate	1	.23	.040 SPS	.15	.25	Δ +.03	.23 / .03	.13
FRONT SEAT FRAME	19.17	.044/ .053 HRS	5.33	21.31	22.97	1	9.59	.060 SPS	5.12	10.66	24.32	9.59 / 1.35	.14
FLOOR PAN ACCESS HOLE COVER	.27	.036 CRS	.07	.28	See Laminate	2	.14	.040 SPS	.09	.15	Δ +.02	.26 / .04	.15
FRONT BRAKE DUSTSHIELD	1.06	.028 CRS	.44	1.74	See Laminate	2	.71	.040 SPS	.71	1.16	Δ +.27	.70 / .54	.77
HUB CAP	.49	.025 AL	.63	.63	See Laminate	4	.33	.030 ANA	.78	.43	Δ +.16	.64 / .61	.95
					*48x62 SHEETS REQUIRED								

(1) AL = Aluminum, CRS = Cold Rolled Steel, HRS = Hot Rolled Steel
(2) SPS = Steel-Polypropylene-Steel, ANA = Aluminum-Nylon-Aluminum, SNS = Steel-Nylon-Steel

identified in this Table is significantly higher, but still less than $1.50/lb. In specific situations, especially in the latter part of the decade, these components might also be made of laminates.

As indicated in Table 1-10, the cost penalty for weight savings for the Omni parts that were examined, ranges from $0.46/lb ($1.01/kg) to $1.80/lb ($3.96/kg). Only the hood inner panel has a weight penalty that it marginally lower than the $0.50/lb ($1.10/kg) current use criterion. It would represent the first use of laminates among the various parts analyzed on that vehicle. The door inner panels and rear seat back panel have higher cost penalties which would make them less likely candidates. The juxtaposition of the door inner panel, and of the door anti-intrusion beam, a safety critical part, might discourage an auto designer from using a metal-plastic laminate for the door inner panel until a better data base were obtained. The high cost penalty of weight savings for the liftgate inner panel, which has a high offal rate, makes this component an unlikely candidate for metal-plastic laminate use.

1.4.6 Current Commercial Status of Metal-Plastic Laminates

This discussion is based on the interviews the principal investigator carried out during the course of the study with the various participants outlined in Table 1-1. These include both potential suppliers of laminates, and potential users. The suppliers include polymer manufacturers, steel producers, aluminum sheet producers, and coil coaters. Potential users include vehicle manufacturers and component manufacturers.

Polymer Suppliers: The polymer suppliers are the most enthusiastic promoters of metal-plastic laminates, and appear to have devoted the largest budgets to this technology. They are able and willing to consider long term R & D programs in order to create a significant, totally new market for their products. U.S. polymer suppliers that have been identified as having an active and visible interest in metal-plastic laminates include ARCO Chemicals Co., Dow Chemical Co., Hercules, Inc., Monsanto Chemical Co., Phillips Petroleum, Inc., and the Novamont Division of U.S. Steel Corporation. Foreign firms with an interest in laminates include BASF AG (West Germany), Mitsui Petrochemicals Inc. (Japan), and Solvey & Cie (Belgium).

Steel Producers: Among the steel producers, there is cautious interest in metal-plastic laminates on the part of manufacturers of tin mill products. In North America, these include Bethlehem Steel Corporation, National Steel Corporation, Stelco Inc. and U.S. Steel Corporation. These companies are pursuing the development of steel faced laminates principally as a defensive measure against the potential inroads of other light weight materials in automotive structures. There is ambivalence in this activity in that if the laminates were brought to successful commercial development, they would be competing against heavier gauge steel sheet, which is a bread and butter item at present for these companies. Laminates would reduce the overall tonnage demand for steel by the automobile industry. However, by offering steel faced laminates, the steel industry would provide the automobile industry a lightweight material option other than aluminum or plastics that contains some steel. While less steel would be sold if steel faced laminates were to replace the all steel sheets now used, this would be a preferred situation to the total displacement of steel in these applications by plastics or aluminum.

The polymer producers viewed laminates as potential proprietary product lines that could support higher profit margins than the individual components taken separately. This attitude was not as prevalent among the steel manufacturers, even though there are strong advocates for laminates within the individual steel companies because they represent an opportunity to sell a product other than a low margin commodity material.

Aluminum Sheet Producers: There is currently no apparent interest on the part of the aluminum industry in metal-plastic laminates for automotive uses. This includes Consolidated Aluminum Corp. which is the only company that has a continuous commercial laminating facility in operation in the U.S. This company is manufacturing and selling thick aluminum-polyethylene laminates primarily for architectural and interior design purposes. It has not active interest in the automotive market, except for specialty situations such as body panels on the Marathon Electric Vehicle, where its existing products can be used, nor in developing thinner laminates that would be required for most automotive applications.

Coil Coaters: The coil coaters have a strong technology and experience base to draw on, as well as facilities for the manufacture of metal-plastic laminates, at least on a semi-continuous basis. The independent coil coaters, however, do not have the resources to perform long term research and development without external support. Arvin Industries, Inc. and Pre Finish Metals, Inc. were two coil coaters identified as having an active interest in metal-plastic laminates. It is quite likely that other firms with similar capabilities share these interests. As previously mentioned, Pre Finish Metals, Inc. has successfully laminated in two passes a 4000 lb (1800 kg) coil of steel-polypropylene-steel laminate on one of its coil coating lines at a speed of the order of 100 ft/min per pass.

Automotive Component and Vehicle Manufacturers: Based on discussions with representatives of General Motors Corporation, Ford Motor Company, and The Budd Company, it appears that there is research interest within different groups at each of the major manufacturers. The work is most focused at Ford Motor Company which has assembled a task force to assess metal-plastic laminates. The results of the study by this task force will be issued this fall. However, metal-plastic laminates are new materials for the automotive industry, and significant further investigation is required before any metal-plastic laminate part is to be qualified for production use. At present, no metal-plastic laminate component is scheduled for use on any production vehicle.

Serious interest in terms of production use of metal-plastic laminates is hampered by uncertainties with regards to:

- availability of metal-plastic laminates
- cost of metal-plastic laminates
- constancy of material properties
- weight savings and performance obtained in tests carried out to date.

These issues have to be resolved before metal-plastic laminates find any use in the automotive industry. In addition, the recent spate of publicity may prove to be counterproductive to this introduction; in that expectations and interest were inflated beyond current capabilities and level of development.

In summary, while there is a general belief that metal-plastic laminates will definitely find their applications in the automotive industry, significant further investigation is required to qualify them for production use. Potential users are looking for improved performance, reproducibility, and lower costs than have been obtained with laminate samples provided to date. Many of the user objections derive from their being supplied with evaluation samples made in a batch mode on platen presses, and on costs based on this manufacturing method. However, before the suppliers are willing to make major new investments in the technology and in continuous laminating facilities, more favorable signals are required from the automotive industry. This impasse may be overcome because improved laminates at lower cost may be made available to the users without the need for major investments in new capital facilities on the part of the suppliers because laminates could be made semi-continuously on existing coil coating lines on a toll basis.

1.5 PROJECTED FUTURE AUTOMOTIVE USE OF METAL-PLASTIC LAMINATES

The user requirements for metal-plastic laminates are the same as for any new, unproven material. These are:

- an identified pay-off
- confidence for less critical applications

o experience for more critical applications

Based on the cost/weight and manufacturing analyses performed, there are a number of automotive components which would be attractive candidates for application of metal-plastic laminates.

Nearer term use of metal-plastic laminates will be in low risk applications where current generation laminates can be used effectively within the constraints of existing automotive manufacturing practice. This curtails the use of laminates to small, non-visible parts that do not have a safety critical function, and where stiffness is the design criterion. Because of cost considerations, laminates will be candidates primarily for parts which have a low offal rate. Furthermore, parts now made of heavy gauge steel (1.25 mm or 0.050 in. and above), to the extent that they are not strength critical parts, would be more attractive than parts made of thinner gauge steel. In general, since parts on light duty vehicles tend to be thicker than the equivalent parts on a passenger automobile, metal-plastic laminates may well be used first on pick-up trucks and vans rather than passenger automobiles. Furthermore, since downsizing is not a viable option for a light duty vehicle designed on a functional basis, weight reduction by material substitution will be relatively more important as a means of achieving improved fuel economy than it will be for passenger automobiles, which can be made smaller and still retain most of their functional characteristics. Representative parts include brackets, access hole cover plates and shrouds. Most of these parts will be made of steel-polypropylene laminates, and will be sufficiently small so that current width constraints on steel sheet will not matter. Total usage of laminates in these applications could be as much as 2.5 m^2/vehicle (29 ft^2/vehicle).

Further use of metal-plastic laminates will be based on increased familiarity with, and confidence in, metal-plastic laminates by automotive designers, and with the availability and use of metal-plastic laminates of lower cost and/or improved performance characteristics. Larger parts may be considered, such as interior panels and load floors, which may require wider laminates (48 in. (112 cm) or more) that are able to withstand passage through the electrocoat primer ovens. It will be necessary to consider nylon 6-6 or thermoplastic polyester core laminates for these applications, since it is believed that the operating temperatures of the electrocoat paint oven will still be too high (greater than 300^{o}F (150^{o}C)) to allow polyolefin core laminates to be used. These applications could present an additional 10 cm^2/vehicle (108 ft^2/vehicle).

Extensive application of metal-plastic laminates which would include their use in exterior appearance parts will only occur with significant changes in automotive manufacturing practice, and thus may never come to pass. The issues of in-plant repair of appearance parts, adhesive bonding, and development of methods of reinforcing attachment points are all problems for which technical solutions exist, and thus could be found, if there were sufficient interest to do so.

A projected upper bound estimate of the use of metal-plastic laminates by the U.S. automobile industry is given in Table 1-12. The reasoning behind this projected introduction is outlined in the more detailed schedule presented in Table 1-13. Initial production use of a small number of low risk parts is unlikely to occur before 1986. If successful, use of laminates in these parts would grow rapidly and could saturate by 1988. This success would justify further use of laminates in similar low risk parts in the 1987 to 1990 period. More extensive use of laminates in larger, higher risk parts on a limited number of production vehicles would follow but would not occur before 1989 to 1990.

Figure 1-2 summarizes the range of the projected demand for metal-plastic laminates based on the automotive use outlined in Table 1-12. This figure assumes a 30% average scrappage factor which is characteristic of the automotive industry. This scrappage level may be high since laminates would tend to be used in parts which have low scrap rates. By 1990, low risk applications would create a maximum demand for about 36 million square meters per year of laminate. This corresponds approximately to the output of two large continuous laminating plants assumed to have a 3 shift capacity of 17 million square meters/year each.

The lower bound estimate would correspond to about 7 million square meters/year which would be sufficient to keep these two facilities operating on a one shift basis. Unless some higher risk applications of metal plastic laminates develop, there would be sufficient demand for two suppliers only. If the higher risk applications come to pass, this could create a demand for an additional 57 million square meters/year which would correspond approximately to the output of three large laminating plants on a three shift a day basis. These additional facilities would be likely to produce a different material than the first two. Based on a nominal selling price of \$5/square meter, low risk applications represent a future business volume of \$35 million/year to \$175 million/year. The higher risk applications would represent an additional volume of \$300 million in 1991, and potentially \$700 million/year if 10 m^2/vehicle were used for the total production, assumed to be 10 million vehicles/year.

These figures indicate that many of the current developers of metal-plastic laminates will drop out since ultimately there will only be sufficient business to support two laminate suppliers if the volume of business is limited to low risk automotive applications. If higher risk automotive applications were to develop, this additional volume could support three additional laminate suppliers. These projections do not include any other potential non-automotive applications of metal-plastic laminates that could develop.

TABLE 1-12

UPPER BOUND ESTIMATE OF PROJECTED AUTOMOTIVE USE OF METAL-PLASTIC LAMINATES

LAMINATE USE PER VEHICLE			
M^2/VEHICLE	0.1 - 0.5	0.5 - 2.5	2.5 - 12.5
PERCENT SHEET METAL USE	0.3 - 1.6	1.6 - 8.0	8.0 - 40.0
YEAR		**NUMBER OF VEHICLES**	
1984 - 1985	2,000*	-	-
1986	400,000	4,000*	-
1987	4,000,000	400,000	-
1988	6,000,000	4,000,000	4,000
1989	-	10,000,000	400,000
1990	-	10,000,000	400,000
1991	-	6,000,000	4,000,000

* TEST VEHICLES

TABLE 1.13

PROJECTED TIME-LINE QUALIFICATION SEQUENCE FOR METAL-PLASTIC LAMINATES

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
IDENTIFY LOW RISK COMPONENTS	———	———										
DEVELOP MANUFACTURING PLAN FOR CANDIDATE COMPONENTS	———	———	———									
DEMONSTRATE SEMI-CONTINUOUS OR CONTINUOUS LAMINATE MANUFACTURING	———	———	———									
ESTABLISH PRODUCT SPECIFICATIONS FOR ABOVE LAMINATE			———	———								
PERFORM COMPONENT FIELD TRIALS IN LIMITED NUMBER OF VEHICLES			———	———								
SMALL FLEET (1,000 VEHICLES OR LESS) OF CANDIDATE COMPONENTS)					———	———						
ESTABLISH CANDIDATE PARTS FOR LARGE FLEET TEST (200,000 VEHICLES EACH WITH TWO MANUFACTURERS)						—						
LIMITED FIELD TESTS OF SECOND GROUP OF LAMINATE COMPONENTS						- - -	- - -					
INITIATE LARGE FLEET TEST - PRODUCTION PLAN FOR FOLLOWING MODEL YEAR							—					
INITIAL QUALIFIED PRODUCTION USE OF METAL-PLASTIC LAMINATE COMPONENTS								X				
LARGE FIELD TESTS OF SECOND GROUP OF LAMINATE COMPONENTS								- - -				
EXTENSIVE PRODUCTION USE OF METAL-PLASTIC LAMINATES IN LOW RISK COMPONENTS									X			
LIMITED FLEET TESTING OF HIGHER RISK COMPONENTS									═══	═══		
SATURATED USE OF METAL-PLASTIC LAMINATES IN LOW RISK COMPONENTS										X		
LARGE FLEET TESTING OF HIGHER RISK APPLICATIONS OF LAMINATES (CONTINGENT RISK)										═══	═══	
INITIAL PRODUCTION USE OF LAMINATES IN HIGHER RISK COMPONENTS												X

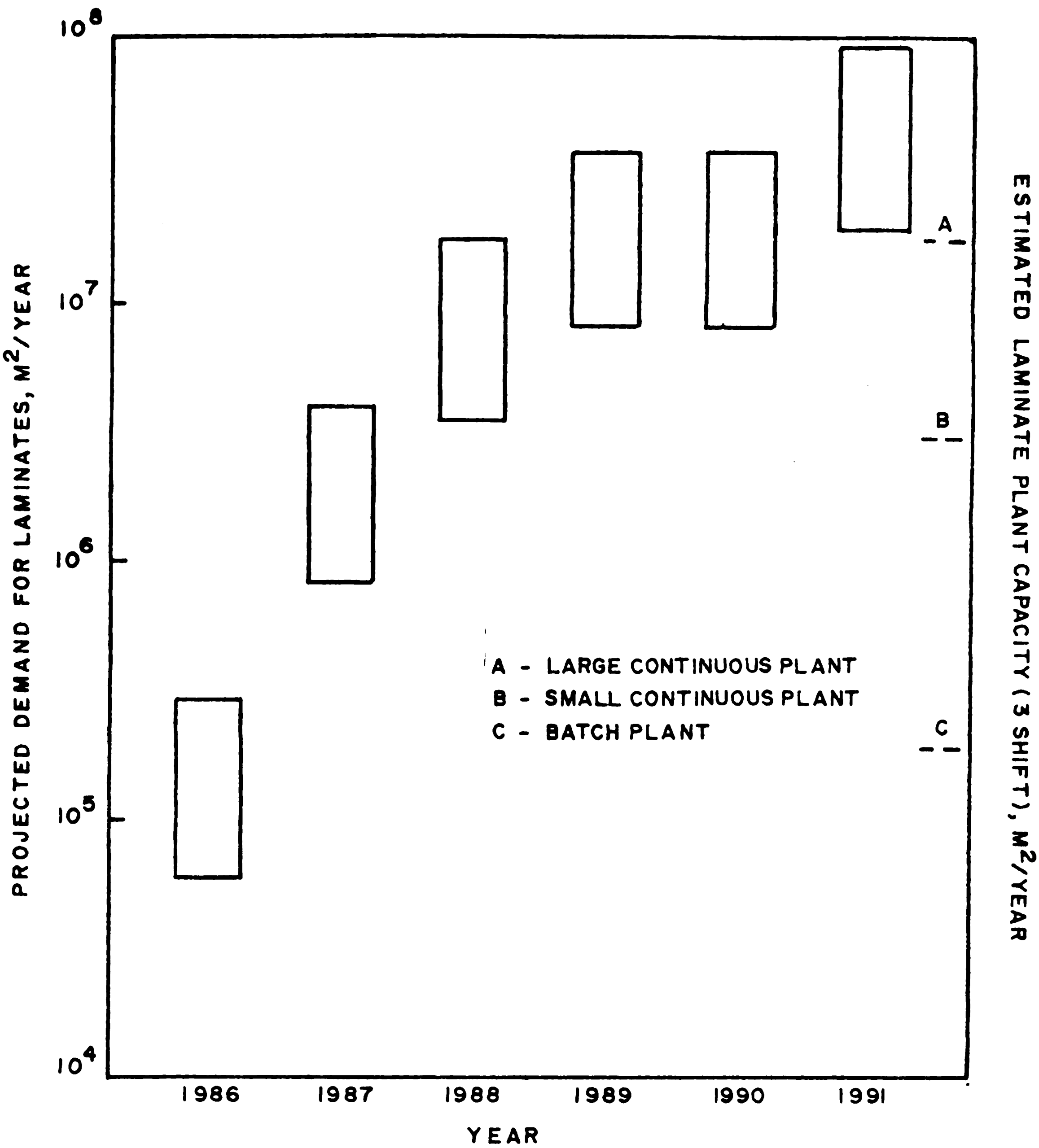

FIGURE 1-2. PROJECTED RANGE OF UPPER BOUND ESTIMATE OF AUTOMOTIVE FOR METAL - PLASTIC LAMINATES FROM 1986 TO 1991.

It is also to be noted that batch plants would not be able to produce sufficient laminate beyond the entry year of 1986, and that small continuous plants could supply the projected use through 1988, but would have to compete with larger facilities that produce laminates at lower cost in 1989 and beyond. Because of this risk of rapid obsolesence of smaller facilities, and because of the ability to laminate on existing coil coating lines on a toll basis at a cost comparable to that of a small continuous laminating facility, it is unlikely that these smaller facilities (i.e., 2 million sq. meters/yr) will be built, except possibly for the manufacture of special grades of laminates where, for reasons of thickness or of safeguarding secret technological know-how, it would not be desirable to laminate at a coil coating facility.

For this projected use to occur, a significant long-term investment will be required on the part of the interested companies, principally the various material suppliers. The automotive and component manufacturers will be interested in using laminates once it has been demonstrated that they are a viable lightweight material in terms of performance, cost and availability. For each candidate application of metal-plastic laminates, the supplier will have to provide the potential user with the information and means required to manufacture the specific candidate component out of the particular type of metal-plastic laminate the supplier wishes to sell. A total system approach is required in which each of the following items will have to be resolved:

- o part design and configuration
- o weight savings and other performance benefits relative to other materials
- o reliability in operation
- o manufacturing plan which identifies equipment and tooling needs, fabrication process details, labor requirements, etc.
- o assurance as to the availability, quality and cost of the metal-plastic laminate that would be used in the application
- o cost advantages (or penalties) of making the specific component out of metal-plastic laminate rather than from a competing product.

Some of the research and development actions that such an effort would require are outlined in Table 1-14. All these action items will require time and money. Items Number 4 (Development of a data base), Number 6 (Cashworthiness Evaluation) and Number 10 (Reclamation and Recycling) would be appropriate areas of research that could be supported by the Federal government.

TABLE 1-14

REPRESENTATIVE RESEARCH AND DEVELOPMENT ACTIVITIES THAT WILL BE REQUIRED TO SUPPORT THE USE OF METAL-PLASTIC LAMINATES BY THE AUTOMOTIVE INDUSTRY

1. IDENTIFICATION AND SYSTEM ANALYSIS OF CANDIDATE APPLICATIONS
2. MANUFACTURING DEVELOPMENT OF SEMI-CONTINUOUS AND CONTINUOUS PROCESS
3. DEVELOPMENT OF NEW LAMINATES WITH IMPROVED PERFORMANCE AND LOWER COST
4. DEVELOPMENT OF A PROPERTIES DATA BASE FOR METAL-PLASTIC LAMINATES OF INTEREST TO THE AUTOMOTIVE INDUSTRY
5. EXAMINE IMPROVED METHODS OF FORMING THIN GAUGE SHEETS IN GENERAL, AND LAMINATES IN PARTICULAR
6. DETERMINE CRASHWORTHINESS OF METAL-PLASTIC LAMINATE COMPONENTS
7. DEVELOP IMPROVED METHODS OF JOINING THIN MATERIALS BY ADHESIVE BONDING APPLICABLE TO AUTOMOTIVE MANUFACTURING
8. DEVELOP IMPROVED METHODS OF IN-PLANT REPAIR COMPATIBLE WITH METAL-PLASTIC LAMINATES
9. MANUFACTURING DEVELOPMENT OF WIDE THIN GAUGE METAL SHEETS
10. EXAMINE CONSTRAINTS ON RECLAMATION AND RECYCLING OF METAL-PLASTIC LAMINATES

Based on the laminate use projected in Table 1-12, metal-plastic laminates will have little impact on the fuel economy of the fleet of automobiles produced through 1990. Based on the weight of sheet metal in a 1978 Omni sedan, as reported in Table 1-2, and an assumed weight savings due to laminate substitution of 40 percent of the weight of the sheet steel replaced, laminate use for 8 percent of the on-board sheet metal, the most optimistic projection through 1990, would represent an average weight savings per vehicle of 23 lbs (10 kg), or one percent of the current curb weight of the vehicle. The fuel economy improvement that would actually be obtained with laminates will be within the uncertainty with which such a projection can be made. If laminates are successfully introduced in the automotive industry by 1990, laminate use should resule in more significant improvements in the fuel economy of post-1991 vehicles.

1.6 CONCLUSIONS

- o Substitution of metal-plastic laminates for sheet steel in stiffness limited components is a conceptually sound approach to weight reduction.
- o Steel faced laminates offer weight savings potential (relative to steel) of 30 to 50 percent; with aluminum faced laminate the weight savings potential is 50 to 70 percent.
- o The polymer core properties significantly influence the manufacturability, cost and performance.
- o Many applications engineering problems still to be resolved. However, selected automotive components could now be made at low risk.
- o No production parts are currently scheduled. North American automotive experience is limited to aluminum-polyethylene laminate body panels on prototype Marathon electric vans.
- o Limited availability and cost of metal-plastic laminates are the major current deterent.
- o With automotive sheet steel at $3.20 per square meter and functionally equivalent aluminum sheet at $7.60 per square meter, metal-plastic laminates must be priced at about $5 per square meter to be competitive.
- o Cost constraints:
  - · Favors steel over aluminum faced laminates even though the latter have a greater weight savings potential.

- Favors the use of low cost polymers for the core. A polymer price in excess of $1 per pound is prohibitively expensive.

- Favors replacement of heavier gauge steel.

- Requires that laminates be made on a semi-continuous or continuous basis.

o Coil coating industry is in best position to capitalize on market, since existing coil coating facilities could be used to make steel faced laminates at an acceptable price.

o While some laminate parts may be introduced in production automobiles around 1985, extensive use of metal-plastic laminates by the automobile industry is at least a decade away.

o Based on the current state of the technology metal-plastic laminates should not be factored in the establishment of AFE standards for 1986 to 1990.