REACTION INJECTION MOLDING

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REACTION INJECTION MOLDING

Preface

The plastics industry has never entered a stagnant period in either growth or development. New products, processes, and applications have been the rule rather than the exception. But even in this dynamic field, the emergence of reaction injection molding (RIM) technology is to be considered remarkable. The pace of RIM development is accelerating so quickly, it is difficult to attempt a "point in time" analysis. This book is our effort to take a stop-action photograph of the fast moving RIM program.

Chapter 1 provides a general introduction and background on RIM development. Differences between RIM technology and conventional cast urethane technology are analyzed. Market history and forecast information is also included.

Chapter 2 provides a basic understanding of the chemical technology of RIM, with emphasis on the contribution of various raw materials to the processing and physical property characteristics of RIM systems.

Chapter 3 is a view of RIM from the manufacturer's standpoint. Included in this chapter are the steps in a commercial RIM process, from raw material receiving and handling through finished part shipping.

Chapter 4 summarizes the commercial development of elastomeric urethane exterior automobile components from the early days of cast and thermoplastic urethane parts to the present, where RIM is the dominant production technology. Product and process improvement, which are necessary for further expansion of RIM, are outlined in this chapter.

Chapter 5 covers the development of RIM in Europe. Emphasis is placed on non-automotive applications and rigid structural foams.

Chapter 6 provides basic guidelines for the design of RIM parts. Emphasis is on the rigid structural foam forms which often are called upon to serve load-bearing functions. The functional requirements for elastomeric materials primarily involve only dimensional stability, impact resistance, and appearance.

Chapter 7 is devoted to the subject of mold design techniques. Procedures are recommended for calculating and designing gating systems. Included is an analysis of various mold materials and configurations.

Chapter 8 covers the important area of RIM machinery. Basic operating parameters for metering equipment, mixheads, and clampings are provided, as well as specific information concerning the operation of various commercial equipment offerings.

In some cases, individual chapters discuss similar aspects of RIM technology. I have attempted to reduce obvious duplications; however, I have permitted areas of multiple coverage to remain if more than one of the authors had a worthwhile contribution or if differences of opinion existed.

Throughout this text, references will continually be made to various standard test methods for evaluation of mechanical performance. Unless otherwise noted, all data presented were obtained per ASTM testing procedures. Several of the authors have chosen to utilize English units in their chapters. A conversion chart is provided in Chapter 1 to simplify the conversion to metric units.

WALTER E. BECKER

Acknowledgments

A complete list acknowledging all of those who have contributed to the development of reaction injection molding (RIM) technology might well constitute a volume in itself. It would certainly be proper to begin with Professor Otto Bayer and his colleagues in Leverkusen, West Germany for their original developments in polyurethane chemistry, which served as the technology base for the development of RIM.

We have been fortunate during the preparation of this book in having the assistance of a number of leading experts in the technology of RIM both here and in Europe. We wish to extend to all of them our sincerest personal thanks for their efforts.

Acknowledgment is also necessary for the many suppliers of raw materials and equipment who have been responsible for RIM's rapid development. These firms have developed a sizable and growing body of literature from which we have drawn. It would be impossible to list all of them, but wherever possible, we have acknowledged specific contributions.

Special thanks go to the many research, development, material, design, and engineering specialists from automobile companies. We are grateful for their enthusiastic reception of RIM as well as for their cooperation with material and machinery suppliers to change RIM's status from that of a laboratory curiosity to that of a commercially successful process in such a very short time.

It has often been said that a good book is a result of 10% inspiration and 90% perspiration, and we are especially grateful to the many persons in Mobay Chemical Corporation for their hard work. Special thanks go to Wally Templin, Joanna Cilli, and, in particular, Florence M. Pippin for her untiring efforts and gracious acceptance of the many, many changes along the way.

Special gratitude goes to Sylvia, Lisa, and Craig Becker for their assistance, encouragement, and—most of all—understanding during the many days when Dad was wrapped up in the book.

Lastly, we should like to pay a very special tribute to the memory of Robert J. Carroll of General Motors Corporation Manufacturing and Development, whose inspirational leadership was a major factor during the first days of RIM development.

REACTION
INJECTION
MOLDING

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Introduction to RIM

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GENERAL BACKGROUND

Why a book totally devoted to the subject of reaction injection molding? RIM has revolutionized plastics processing, and over the next 20 years it will be the fastest growing sector of the plastics industry. Thus, it is unquestionably a sufficiently important topic for a book.

RIM involves the injection of a reactive liquid mixture–in most cases polyurethane or polyisocyanurate–into a closed mold where chemical curing and expansion take place Fig. 1-1. A finished part is removed in 1-10 minutes, depending on the chemical system, the part thickness, and the capabilities of the processing equipment.

Table 1-1 is a brief summary of the major tests methods now utilized to evaluate the performance of RIM components.

The best indication of the tremendous rate of RIM development is the fact that there was essentially no consideration of the future of RIM in the two-volume treatise on polyurethanes by Drs. J. H. Saunders and K. C. Frisch[1] in 1962-1964. An excellent work, *Advances in Polyurethane Technology,*[2] published in England in 1968, also largely ignored this area. Even as late at 1969, Wright and Cumming published a fine book, *Solid Polyurethane Elastomers,*[3] which failed to mention RIM. These omissions are understandable because the first RIM applications did not appear publicly until approximately 1966 and received little or no attention until the introduction of the Bayer AG all-plastic car at the K-67 Plastics Fair in Germany. This demonstration vehicle was the first dynamic exhibit of the possibilities of RIM-produced automotive parts. To many industry observers, the Bayer car was the catalyst which started the RIM reaction.

The original question–"Why a book on RIM?"–might be rephrased "Why is there so much interest in RIM?" The individual chapters will answer this ques-

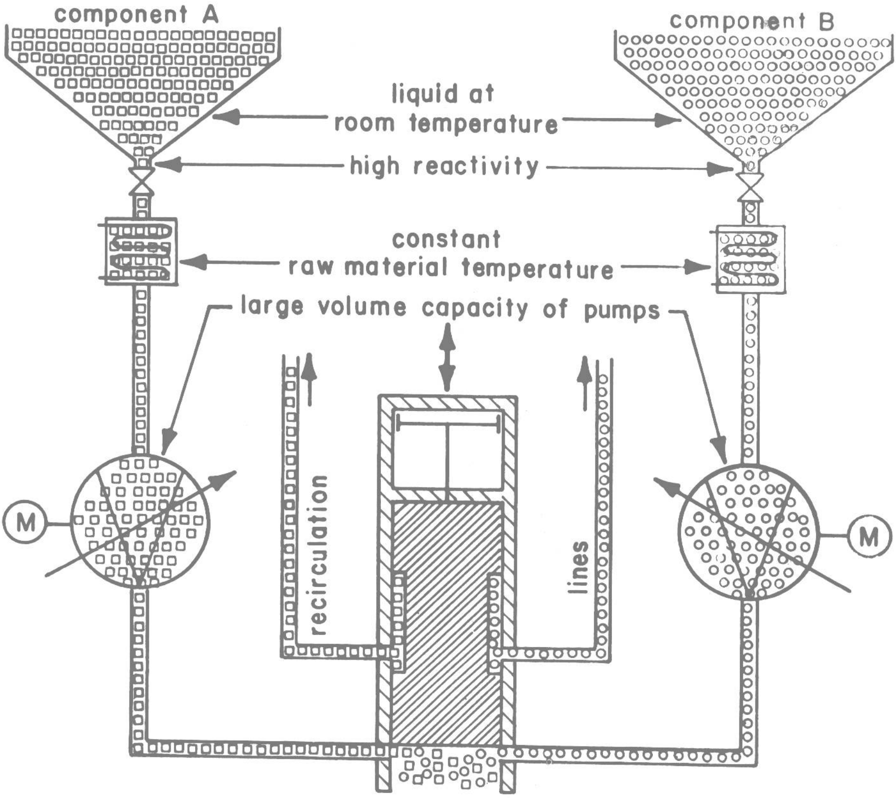

Fig. 1-1. Schematic diagram of the RIM process.

TABLE 1-1. Test Methods for Evaluation of RIM Materials.

*Property or Test**	*Method*
Specific gravity	ASTM D-792
Tensile strength	ASTM D-412
Elongation, %	ASTM D-412
Die C tear	ASTM D-624
Flexural modulus	ASTM D-790
Density, lb/ft^3	ASTM D-1622
Shore D hardness	ASTM D-2240
Tensile modulus	ASTM D-412
Sag, 4 in. overhang, 1 hr, 250°F	CTZ ZZ006AA**
Flexural recovery, degrees recovered after 5 min	CTZ ZZ003AA**

*Table 1-2 gives the multiplication factors by which one can convert metric to English units, and *vice versa*.

**Specifications of Chevrolet Motor Division of General Motors Corporation.

TABLE 1-2. Metric/English Conversion Chart.

	To convert from:	*To:*	*Multiply by:*
Weight	Pounds (lb)	Kilogram (kg)	0.4536
	Kilograms (kg)	Pounds (lb)	2.2046
Length	Feet (ft)	Meters (m)	0.3048
	Meters (m)	Feet (ft)	3.2808
Volume	Cubic feet (ft^3)	Cubic meters (m^3)	0.0263
	Cubic meters (m^3)	Cubic feet (ft^3)	35.3144
	Gallons (gal)	Liters (l)	3.7854
	Liters (l)	Gallons (gal)	0.26417
Density	Pounds/cubic foot (pcf)	Megagrams/cubic meter (Mg/m^3)	0.0160
	Pounds/cubic foot (pcf)	Kilograms/cubic meter (kg/m^3)	16.0180
	Kilograms/cubic meter (kg/m^3)	Pounds/cubic foot (pcf)	0.0624
Tensile strength/flexural modulus	Pounds/square inch (psi)	Kilograms/square meter (kg/m^2)	703.1
	Pounds/square inch (psi)	Megapascals (MPa)	0.006894
	Megapascals (MPa)	Pounds/square inch (psi)	145.0
Tear strength	Pounds/lineal inch (pli)	Newton/meters (N/m)	175.1

tion in detail. For now, however, the key advantages of RIM which the reader should bear in mind are listed below.

Low energy consumption. RIM provides the lowest energy-consuming route to a finished part.

Large part size. Parts larger than 100 pounds have already been produced via RIM. Injection molding equipment to produce such large parts, even if technically possible, would be cost prohibitive.

Complex part capability. Large parts of varying cross section with inserts can be produced without the sink mark problems of injection molding operations.

Paintable surfaces. Absolutely swirl-free surfaces are obtained because of the low initial viscosity of the reaction mix.

Lightweight parts. Due to the microcellular structure, RIM parts offer automobile component weight reduction and coincidental improvement in gas mileage.

Corrosion resistance. As plastics, RIM-produced parts are more corrosion resistant than metal parts, and thus are better suited for automotive exterior parts.

Variable chemistry. Depending on the chosen chemical system, parts can be produced over a wide range of flexibility, from rigid structural foam types to highly flexible automotive interior padding and exterior impact resistant parts.

Lower capital investment. This is due primarily to the lower molding pressures involved.

One warning would be appropriate: While RIM offers lower cost advantages, it should not be considered a cheap process. A company contemplating an investment in RIM would be very unwise to opt for a "garage shop" operation in order to save on capital investment. Such a decision will lead to an inefficient (or even inoperable) plant and high operating costs, which will be a burden for many years. Of particular concern is the necessity to obtain a satisfactory mold. RIM chemical systems will perfectly duplicate the mold surface, including all flaws.

When a company is considering investing in RIM, one or more companies noted as RIM equipment and raw materials suppliers should be consulted; their judgments, which are based on practical experience, can be relied upon.

Every technology breakthrough is accompanied by a host of new terms. While "RIM" appears to have gained universal acceptance, other designations have been given to the process:

Liquid reaction molding (LRM)
Liquid injection molding (LIM)
Liquid injection molding of elastomer (LIME)
Liquid reaction injection molding (LRIM).

For the sake of simplicity, in this text, the authors will refer to the process as RIM.

CAST URETHANE TECHNOLOGY

The word "revolutionary" is often abused and over-used when describing new technologies. However, it is difficult to select a previous existing technology from which RIM could be considered an evolutionary step. The technology area which most nearly fills that requirement is that of cast urethane elastomers. For this reason, a brief description of casting technology is appropriate.

The basic chemical technology of cast polyurethane elastomers was covered in detail by Saunders and Frisch.[1] A typical procedure used in a urethane casting operation in 1960 involved several steps, these are outlined below.

Step 1. Diisocyanate and polyol (polyether or polyester) were mixed at temperatures of approximately 130°C and held at that temperature for several minutes.

Step 2. A chain extender (glycol, amine, or a mixture of glycol and amine), in an amount slightly less than stoichiometric, was stirred in.

Step 3. The mixture was poured into a waxed metal mold having a surface temperature of 100°-120°C, where polymerization and preliminary cure occurred.

Step 4. When the polymer reached a level of strength sufficient to permit handling without damange (generally 20-30 minutes), it was demolded.

Step 5. The demolded part was then post-cured for 10-15 hours at 100°C to complete the cross linking reaction.

From 1960 to 1970, many improvements occurred in the casting operation.

1. Prepolymers were made commercially available, eliminating the necessity for the urethane producers to carry out the often difficult prepolymer manufacture (*Step 1*).
2. Process machinery was developed to semi-automatically meter, mix, and dispense the urethane ingredients.
3. Systems with greater reactivity reduced the demolding time to 9-10 minutes (*Step 4*).

In the early 1970's, it became clear that casting technology had reached a limit of development, both technically and commercially. Furthermore, it was recognized that any greater penetration of urethane elastomers, particularly into industries geared to high speed production, such as the automotive industry, would require a drastic reduction in cycle time. Clearly, there was a demand for chemical systems with much greater reactivity as well as an upgrading of process technology and equipment that would permit handling of such faster systems. This challenge formed the basis for RIM development.

MARKET OUTLOOK FOR RIM

In discussing the market possibilities for new technologies, one always runs the risk of being overly optimistic, particularly with respect to rate of volume growth. This has been the case with RIM. Early forecasts made in 1970-1975 suggested the growth rate pattern given below.

	1975	*1980*	*1985*
Rigid RIM, millions of pounds	20	90	330
Elastomeric RIM, millions of pounds	10	100	220

Much of the optimism for rigid RIM was based on equally optimistic forecasts for structural foams in general. In the early 1970's, most forecasters were predicting 1980 markets for structural foam on the order of one billion pounds. The significant advantages of RIM over thermoplastic structural foam suggested that a level of about 10% of the structural foam market could be easily captured by rigid RIM. While the basis for optimism regarding rigid RIM versus thermoplastic structural foam remains as sound today as it was then, the overall growth prospects for structural foams are evaluated more conservatively.

Similarly, optimism abounded for the elastomeric RIM area. Nearly every industry forecaster took the maximum weight of polyurethane fascia that could be considered (with no consideration of forthcoming downsizing programs) and multiplied this pounds per car value by ten million units per year. Most forecasters did concede that 100% penetration would be difficult to achieve by 1985; thus, the numbers, while grossly overstated, were not as far out of line with reality as were those for the rigid RIM sector.

A more realistic outlook for RIM market development is shown below.

	1977	*1978*	*1980*	*1985*
Rigid RIM*, millions of pounds	3-4	6-8	15-20	40-50
Elastomeric RIM, millions of pounds	10	30	50	110-130

Without question, the largest single growth area for RIM-molded parts between 1970 and 1976 was the automotive sector. The motivation for this growth is illustrated in Fig. 1-2, which clearly shows the impact and damage resistance of this elastomeric RIM fascia. If accurate calculations could be made, it might well be that 90% or more of all raw material consumption in the RIM application area would have been represented by automotive applications. This picture has

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*Excluded from the rigid RIM category are high density, 20-40 pcf, non-integral skin rigid urethane foams which have found usage for wood simulation. The usage or rigid urethane foam for wood simulation was estimated to be approximately 15 million pounds in 1977.