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Distribution:
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E/WT.13/18
24 September 1972

United Nations Industrial Development Organization

Original: ENGLISH

Symposium on the Development of the Plastics
Fabrication Industry in Latin America

Bogotá, Colombia, 20 November - 1 December 1972

ADVANCES IN PLASTICS POLYMERS AND RESINS FOR
IMPROVED AND EXPANDED APPLICATIONS ^{1/}

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ITD/WG.14/RS SUMMARY
19 September 1972

Original: ENGLISH

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SUMMARY

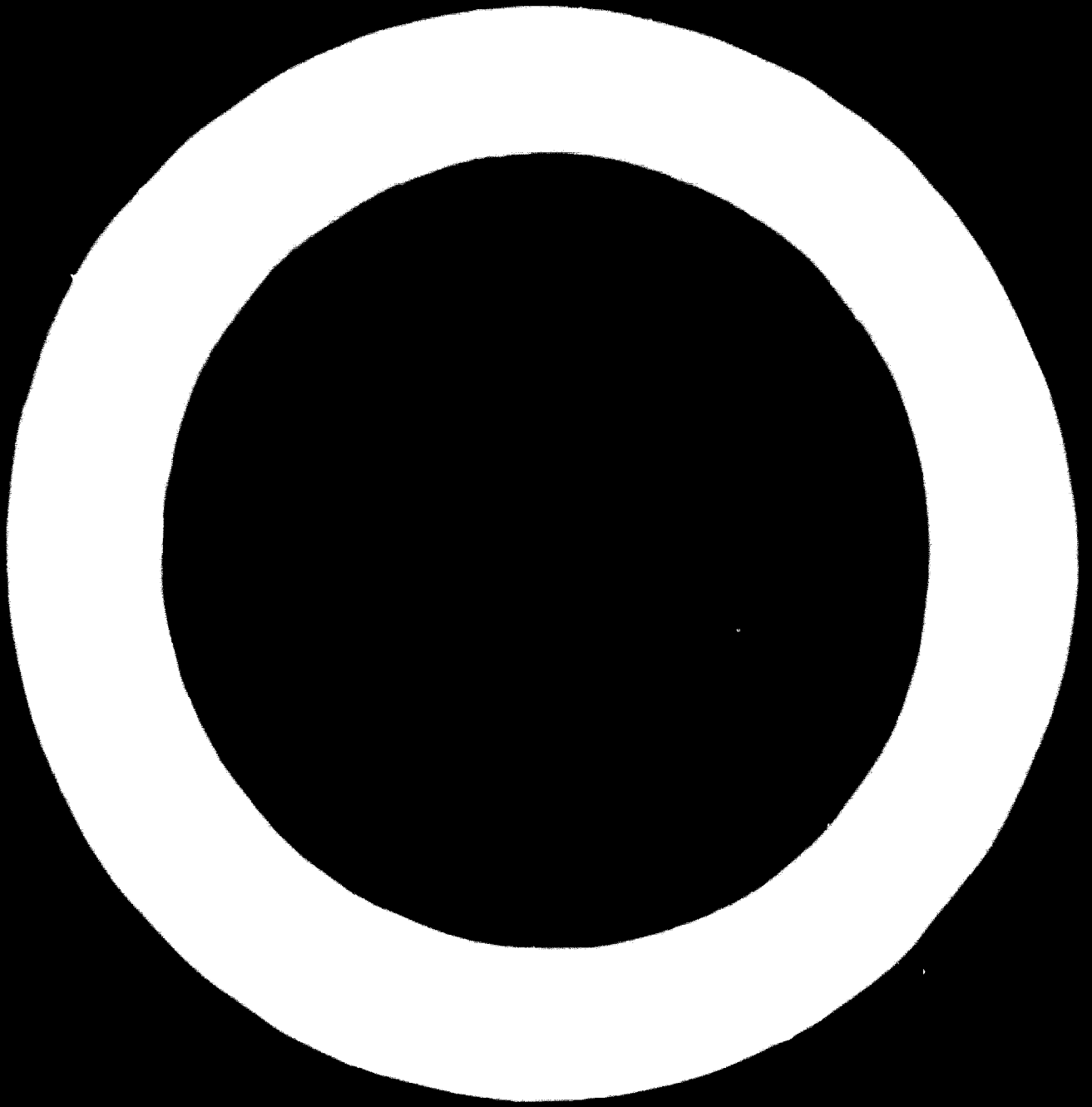
ADVANCES IN PLASTICS POLYMERS AND RESINS FOR
IMPROVED AND EXPANDED APPLICATIONS

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Plastics materials and resins are derived from high molecular weight polymers endowed with enormous variations and possibilities in molecular weight distributions, narrow and broad, and in spatial arrangements with molecular chain modifications in crystallinity, orientation, and cross-linkage. While these molecular features are not commonly considered in the usual characterization or specifications in plastics technology, they are constantly under development and fundamental scrutiny in the area of basic polymer science quite removed from the more practical considerations of fabrication and mechanical performance. Many innovations and advances in plastics stem from relatively minor changes or adjustments in the processes involved in the polymerization leading to major effects. In effect, these changes have been achieved often with little or no major changes or additions in capital investment of existing polymer production facilities. Thus, even old-line established plastics, locked-in

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to existing materials. The most important developments in this area are the unique opportunity for improvement of the mechanical properties of polymers that are frequently used in applications where high strength and impact resistance are required. This is achieved by the use of high impact polymers, which are developed by the use of special catalysts and improved properties with high mechanical strength and impact resistance.

The improvement and modification of polymers can be achieved in many ways: (a) by structural modification of the polymer repeat units, (b) by cross-linking, (c) polymer blends or alloys, and (d) by the use of fillers, such as glass fibers and inorganic micro-fibers. In addition, new polymers are being developed for improved fabricability, improved outdoor weathering resistance, reduced toxicity upon incineration, and ready bio-degradability. Specific examples are discussed to illustrate the growing importance of up-grading existing chemical types derivable from extant production facilities of developing countries.

Polymer derived from styrene, ethylene, propylene and their olefin homologs from petrochemical technology have shown several important innovations. The example of polystyrene to gain impact resistance and increased distortion temperature has been achieved by augmenting the polymerization with diolefins. Thus this simple technology, attained by copolymerization of two olefins or with diolefins to gain cross-linking, has given rise to new groups of plastics for expanded fabrication technology. A new high density polyethylene is available in a cross-linkable grade for rotational moulding into large capacity fuel tanks, agricultural chemical tanks and special trash containers, to illustrate the opportunities with an established polymer modified with α homologous monomers.

Polymer blends or alloys are gaining incremental improvements each year. In the long run, these provide ever-increasing penetration of plastics into areas held by light metals, a case in point being the acrylonitrile-butadiene-styrene (ABS) copolymers especially as metal-platable plastics.

Compositions of plastics with inorganic fibers are now taking a significant segment of plastics applications, access practically all of the principal chemical types of polymers including the specialty, high temperature polymers. Although glass fibers proffer outstanding cost merits with respect to enhanced mechanical properties and endurance, competitive molecular fillers, notably titanates show merits in not only higher tensile constants but also in reducing the thermal co-efficient of expansion closer to that of light metals.

This, together with the fact that the type of material that has been used in plastics for increased fabrication into fabric, can now be derived from existing plastics production in a wide range of materials. In competition with chemical innovations created with unique aromatic esters, the poly-ene polymers can be expected to prefer their own innovations for a range of applications.

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PURPOSE OF THIS PRESENTATION

This presentation is intended to provide a topical review of the advances in plastics technology with an attempt to demonstrate that old-line established polymers will continue to reflect growth in production and consumption by virtue of latent potentials in interrelated areas of basic polymer structure and fabrication technology. This interrelationship and in fact an interdependence is providing expanded opportunities. At the same time, existing monomer types should play an important role in growth by adjustments not only in macromolecular configurations but also by blends and reinforcing compositions. It is thus intended to demonstrate that although new polymers may be forthcoming, the old-line established ones still have inherent unexplored merits to be exploited.

I. INTRODUCTION

Plastics materials and resins are derived from high molecular weight polymers endowed with enormous variations and possibilities in molecular weight distributions, narrow and broad, and in spatial arrangements with molecular chain modifications in crystallinity, orientation, and cross-linkage. While these molecular features are not commonly considered in the usual characterization or specifications in plastics technology and commerce, they are constantly under development and fundamental scrutiny in the area of basic polymer science quite removed from the more practical considerations of fabrication and mechanical endurance. Many advances and innovations in plastics stem from relatively minor changes or adjustments in the processes involved in the polymerization and blending operations leading to major effects (1). In effect, these changes have been achieved often with little or no major modifications or additions in capital investment of existing polymer production facilities. Thus even old-line established plastics, locked-in to existing monomer and polymerization facilities, have an equal and often unique opportunity for the marketplace as well as any new chemical types that are frequently more expensive than the old-line plastics. For instance, the old-line polymers and copolymers of styrene, which in the early years were brittle with poor or inadequate impact resistance and inadequate heat distortion temperature, gradually acquired improved properties with high

impact resistance and increased heat distortion temperatures.

The innovations and advances with old-line, established polymers take form in such ways as (a) fine structure modifications in the arrangement or orientation of the polymer repeat units, (b) cross-linking with co-valent and ionic bonding, (c) polymer blends or alloys, and (d) composites with fillers, such as glass fibers and inorganic micro-fibers. In addition, new resins are being developed for improved fabricability, improved outdoor weathering resistance, decreased toxicity upon incineration, and degradability after use and disposal. Specific examples are discussed to illustrate the trends and increasing importance of modifying existing types of polymers and plastics derivable from current petrochemical monomers and existing production facilities.

II. CONVENTIONAL, ESTABLISHED POLYMERS AND RESINS

The plastics industry as a whole comprises two distinct types of polymers or resins, the latter referring generally to the form ready for fabrication or conversion into a formed object while the former as implied in this discussion relates to the principal molecular features in the chemical and physical sense. These are (a) thermosetting polymers or resins that start from low molecular weight entities or mixtures and depend upon consequent thermal reactions to gain high molecular weight by the condensation reactions, and (b) thermoplastics that maintain their initial high molecular weight structure throughout the consequent fabrication or shaping operations. In more recent years the latter have been accorded special

agents to impart molecular orientation to the polymer, either by increasing the chain length of the polymer, or by intra-chain linkage, common to many of the polymer linkages. The discussion on the hard polymer type is not intended in this presentation, but is merely presented to indicate the past pattern of intense efforts of improvement and innovation expended in behalf of both types of plastics and the consequent, steady growth of both as important materials in broad range of applications.

Thermosetting Resins

As a long-established class of condensation polymers first developed in 1906 by Dr. Leo H. Baekeland into a major segment of the plastics industry, the thermosetting phenolic class of thermosetting resins continue to maintain a dominant growing position in plastics technology by virtue of (a) modified, improved product forms for specific fabrications, (b) modified and improved fabrication machinery and moulding accessories, and (c) regulatory devices for the control of thermal cycles and curing conditions for efficient, low-cost manufacture. Each of these features in themselves represent significant advances resulting from years of fundamental investigations on condensation mechanisms and rheological changes with thermal exposure, and which continue to serve as the mainstay for technical improvements for thermosetting plastics. The early, pioneering phenolic resins of Dr. Baekeland have over the years been further supplemented by other important types of urea-formaldehyde, alkyds, and other thermosetting resins.

As a consequence of the above-mentioned three means of resin modifications and improvements, the seemingly dormant or slow growth of the thermosetting resins in the past decade have experienced a pronounced upsurge, considering the case of the five-year production figures, from 1966 to 1972, for the plastics data reported in the United States of America and shown in Table 1 (2). What was once considered as a resin type in competition with the ever-growing usage of thermoplastic resins notably the acrylonitrile-butadiene-styrene (ABS) polymers, the old-line thermosetting resins continued to maintain a growth rate over the span of years substantially equivalent to, or on par with the growth rate of thermoplastics as discussed in the ensuing comments. The U.S.A. production statistics for the plastics, used in this presentation as a bell-weather indicator or forecaster of what would could transpire in other quarters or regions of world, reflect a significant 23 percent increase over the past five year span tabulated. Following a significant loss in 1969, the thermosetting resins market regained much or almost all of the loss, rejuvenated by the advances especially in the adaptation of the condensation types, especially the polyesters, into filler-extended or reinforced resins. The upsurge according to statistics was impelled especially by the construction boom for which the above-mentioned three features of resin improvements and fabrication technology provided the important technical and economic roles.

The noteworthy advances in the competitive, dominant position of the thermosetting resins in comparison with that of the thermoplastics, notable polyolefins, is due largely to the construction boom, as illustrated by the data from the U.S.A. statistics, and the attendant increases in the injection moulding technology of appliances, electrical insulation, automotive components and myriad of other fabricated articles. A review of the trade literature for thermosetting types and grades of resins discloses a marked trend by suppliers to furnish specific resin grades to specific fabrication and end-uses to assure the economic stance of the thermosetting market. It is not unusual to find that a supplier will offer as many as 20 grades and variations of a thermosetting resin, designed or tailor-made, as is the common parlance, to the moulding operation or the end-use article or combinations of the two. Much of this specificity is proprietary, and more often defined in empirical specifications rather than in terms of physical or rheological constants. Thus the know-how in this sense on the part of the resin producer is keyed to the unique formulation and control of the resin stage of condensations. The sustained dominance and growth of the thermosetting resins represent significant, though obscure advances in adjusting and modifying the resin ingredients including extenders and fillers, along with modifications in the condensation reactions and rheological characteristics taking place during moulding operations. Empirical as

this may seem, there is still an appreciable amount of basic and fundamental investigations on the complex mechanisms involving (a) preparation of the resin stock and (b) understanding the conversion of the various thermosetting structures of the phenol-formaldehyde, urea-melamine, polyesters and epoxide resins.

As is indicated in Table 1, the polyester resins have grown even faster than the phenolics, attaining a 33 percent increase in the 1966 - 1972 period. Much of this rebound from the seemingly indeterminate growth is ascribable to reinforcement with glass fibers, in which case the construction boom has played a major role in impelling the advance. The polyesters indicate an increasing level to that of the melamine-urea resins also as a consequence largely due to reinforcement with glass fibers, while the melamine-urea resins continue their major role in the adhesives applications. The epoxides, lowest members in the annual volume and growth statistics, continue to serve primarily the protective applications.

Thermoplastic Polymers

As another established class of addition polymers, differentiated from the foregoing thermosetting condensation class, the thermoplastics continue to show annual production increases. Based on the annual U.S.A. statistics (3) shown in Table 2, the figures indicate a balance of supply and demand and can be viewed as the bell-weather indicator of the

goal or expected balance proportions of the various plastics in other regions of the world economy. The balance of supply and demand as well as the product mixture provides one measure of planned investment in the broad range of plastics as well as advances in each area of the polymer structural types as an interplay of monomer production, fabrication technology, and aggressive marketing and product design.

According to the U.S.A. statistical summary in Table 3, production of low and high-density polyethylene has netted 18 and 25 percent gain in the first-half 1972. Approximately the same level of growth apparently is experienced with the older poly-styrene and polyvinyl chloride. The most prominent increase is reflected with polypropylene with an increase of 24 percent for the equivalent period.. Survey of the published and patent literature indicate an ever-increasing awareness of the role of molecular weight and molecular weight distributions and the branched structure or linearity of the macromolecular chains, a feature to a large measure regulated and controlled by the polymerization processes at the point of manufacture. Still another area of molecular innovations is related to the orientation of the macromolecular chains after the fabrication process, the example being the case of orientation with polypropylene leading to a variety of such extruded and fabricated items as monofilaments, films, and strapping with a new range of tensile characteristics that have served to extend the market outlets for this polymer to the exceptionally high surge of 37 percent as indicated in Table 3.

In retrospect, it is important to examine the trends as indicated by the statistics for the U.S.A. plastics production figures as a planning exercise from the standpoint of future requirements coordinating the petrochemical capacity for specific monomers in relation to polymer modifications in the old-line established plastics so that a sound economic balance can be devised for given national or regional expansion plans. It is evident that no one type or class of plastics will sustain the balanced proportions of the various types of polymers. Both expansions and polymer modifications will continue to affect this balance from year to year. This will require ever increasing research and development in new directions that include the combined areas of polymer reactivity as part of the fabrication technology along with innovations and new engineering of fabrication equipment, moulding, extrusion and their newer adaptations.

Reactive Polymers and Fabrication Engineering

What has just been stated to this point is that the growth of the plastics industry to a large degree has resulted from technology exploiting the reactivity of the polymer during fabrication into modified macromolecular structures notably cross-linked, stronger types of plastics. Thus reactive polymers compounded with cross-linking ingredients are emerging as an important class of novel polymers in their own right. This applies to both the conventional thermosetting

as well as the thermoplastic categories. The fabrication engineering features involve new designs of equipment. A noteworthy case in point are two innovations, such as depicted in Figure 1: namely,

- (a) injection-mixing (IKM) and
- (b) injection moulding under ultra-high pressures.

Key to the features of these two processes is the regulated control and transient adjustment of the critical thermal dwell time within the narrow range that sustains flow simultaneously with the necessary sintering by coalescence (4). The concept is applicable not only to conventional thermosetting resins but also to the more recently developed cross-linking thermoplastics, notably those derived from polyolefin macromolecules. This concept, which in effect borrows from the classical reactivity during fabrication in the case of the thermosetting resins, is expected to develop a significant segment of the plastics market. Technical developments along this line are already illustrated by the work with cross-linkable polyethylene of varying molecular weights (5) such as is depicted by the selected tensile data in Table 4. In this instance, it is clear that molecular weight is an important factor in developing the tensile constants and will require further study in relation to the desired balance between the physical properties and the sensitivity to chemicals such as rated by the solubility in toluene shown in the Table 4. The latter emphasizes the profound effect on chemical properties. Thus the solubility in toluene is reduced significantly, a

feature that would be indicative of resistance to edible and mineral oils when used as containers for such diverse applications as vegetable and mineral oils. While the illustrative data in Table 4 at the present stage of development appear marginal in enhancing the stressing properties, this approach to the growth of established polyolefin polymers and their copolymer analogs will bear close watching for plastic modifications that should continue to penetrate container and other applications.

Simultaneously with the advances in the macromolecular modifications during fabrication are the engineering innovations in processing, fabrication equipment. Plastics fabrication with screw type and plunger type injection moulding machines proffer both parts engineering and economic merits. A particular case in point is adaptation of polyethylene, purposely prepared as a high density cross-linking moulding compound, for rotational moulding (6). The combined innovation of polymer with fabrication offers impact strength, environmental stress-cracking resistance and overall general toughness previously unavailable from the parent type of polyethylene. Some of the current applications which have utilized the overall general toughness of cross-linkable high density polyethylene include fuel tanks, agricultural chemical tanks, and large trash containers, in sizes from 50 to 500 gallons. Cross-linkable high density polyethylene containers are claimed to have been in use over a year in rigorous trash collection service. It

can be expected that the same concept of cross-linking during rotational moulding, with appropriate polymer variations and design of the engineering components of the rotational moulding equipment will be extended to other polymers. On a fundamental basis, the theoretical features of rotational moulding in relation to sinter melting (7) are already being investigated to regulate polymer reactivity in the confines of the moulding conditions.

Degradable Plastics

With the world-wide concern over litter of discarded artifacts that include plastics items, the need for degradable plastics is gaining increasing emphasis in the innovation and modifications of old-line established polymers. Principal effort is being directed along two lines, hydrolytic degradation and photodegradation, the latter having displayed more immediate extensive commercialization. Polymer suppliers are providing new compositions of polyolefins modified with specific additives that enhance photodegradation using photosensitive structures. Photodegradable packaging films and bottles are emerging on the market based on proprietary photosensitizers and also polymer structures that deteriorate into embrittled and products.

The degradation period under exposure to sunlight of plastics ranges from two weeks to six months depending upon the amount of the photosensitive agent incorporated into the plastic (8). Some of the photosensitizing agents have already

been cleared in some countries for use in food packaging and containers. The price increment according to some sources is not higher than 20 percent above that of the equivalent grade of parent polymer. There are several methods of incorporating the photosensitizing agents. The next few months will witness numerous technical variations such as (a) adding the photosensitizing ingredient during the forming of the fabricated article and (b) adding the photosensitizing agent during the polymerization or polymer finishing operations at the source of manufacture. A new era is being opened up along several fronts for innovations and advances, such as developing macromolecular points of sensitization with comonomers in the polymerization and synthesis of new organic structures that are purposely made to be labile until exposure to sunlight.

The general mechanism for photodegradability is depicted in Figure 2, following the generalized mechanisms:

- (1) ultraviolet light energizes the photosensitive agent or component of the polymer chain,
- (2) the energized agent captures a hydrogen, or proton, from the polymer chain,
- (3) the polymer radical now captures an oxygen molecule from the air, or water producing a peroxy radical,
- (4) the peroxy radical captures a hydrogen atom or proton from another polymer becoming a hydroperoxide, while the second polymer becomes a radical, and finally,
- (5) the perhydroxide breaks down into shorter chains and water.

A typical polymer chain in the case of polystyrene of about 1400 units breaks down to chains averaging 200 to 300 units in length.

Other photodegradable polymers are being developed without the use of photosensitizing agents, a feature so special merit for food packaging and possibly to avoid toxic pollutants. The particularly noteworthy case is that in which polymers on aging with or without exposure to light gradually acquire increasing level of crystallinity to the point of becoming extremely fragile and sensitive to impact or crushing stress. This feature can be achieved by the control of the molecular weight and by the incorporation of comonomers that are interspersed in the macromolecular chain. The latter is typified by the recent introduction of 1, 2-butadiene as a new type of polymer source for developing fragmentable plastics after photodegradation. In retrospect, it is evident that a new areas of polymer modifications in the existent petrochemical technology is being launched in consonance with the inevitable demand for disposal plastics that meet the ever-impending restrictions against litter and pollution.

III. POLYMER BLENDS (POLYMER ALLOYS)

Polymer blends or alloys, as the term is gradually becoming popular, are gaining significant, incremental applications with improvements and innovations in properties that favor their use in many articles for construction and appliance. The principal base polymers are the acrylonitrile-butadiene-styrene

(ABS) types which are available in an extensive variation of grades and characteristics. Endowed with the polar nature of the -CN configuration of the acrylonitrile component and the relatively low viscosity of the styrene-acrylonitrile (SAN) rigid glass phase, the ABS polymers can be alloyed with various other polymers to create new resins that extend the broad range of engineering properties (9). As indicated in Table 5, these include alloys with polyvinyl chloride (ABS/PVC), polycarbonate (ABS/PC), and polyurethane (ABS/PU), as well as others that may be expected in time to gain equal prominence.

ABS/PC Alloys. ABS is an effective impact modifier for rigid PVC, which in turn provides self-extinguishing characteristics. Both rigid and flexible ABS/PVC alloys are available for various moulding operations and sheet calendering (10). Clear bottle compounds are made from special types of ABS modifier that impart high degree of clarity in addition to improving the process ability and impact properties. In flexible compounds, ABS as an alloying component improves formability, shrinkage, and retention of the embossed grain patterns.

ABS/PC Alloys. These alloys provide a balance of rigidity, impact strength, and heat resistance at a price intermediate to that at low priced ABS and the high priced polycarbonates. They are useful in thermoformed sheets and injection moulding articles that require dimensional stability at temperatures above 110 to 115°C. and high impact at temperatures as low as -50°C. Typical and most popular applications are for protective

headgear for construction workers and for motorcycles.

ABS/PU Alloys. The alloying with polyurethane elastomers produces products with high impact strength. The melt flow of this type of alloy is equivalent to that of the general purpose ABS parent polymer, and is particularly suited for the production of thin wall parts.

Many ABS formulations are specially designed and devised for a variety of fabrication techniques and adaptations that include cold forming, expansion casting, and particularly electroplating to impart a metal-like finish or appearance.

Cold Forming. Standard metal forging equipment with minor mechanical and heating appurtenances can be adapted to cold forming ABS sheet stocks and billets in making articles ranging from food packaging, to automotive and other industrial and engineering componets. Sepcially formulated grades of ABS containing lubricants are gradually being adapted to forging operations using heated drawpads and punches.

Expandable. Numerous proprietary grades of expandable, low density forms of ABS resins are becoming available for injection moulding and expansion casting into structural rigid foam materials.

Electroplating. ABS grades of polymers have been developed especially for high adhesion and surface appearance of the deposited metal plate. These are designed purposely to withstand the endurance requirements and specifications involving thermal and cold cycling for exterior applications, in particular

automotive grills. Although there is some competition from polypropylene, the ABS polymers maintain a preferred position by virtue of dimensional stability recently enhanced with acicular titanate filler (11), moulding ease into exceptionally smooth topical finish and appearance, and overall cost advantage of the final plated products compared to die casting of metal. Plating onto the plastic surface replicates the perfections or imperfections of the plastic underlay. Hence, much proprietary technology exists in the selection of the grade of the ABS base polymer most suited to the high finish smoothness. A wide variety of decorative effects are produced ranging from embossed surfaces to mirror-like finish with a variety of electrodeposited metals such as chromium, copper, nickel, and silver.

In general, the ABS polymers and especially their alloys can be expected to develop significant penetration into the myriads of fabricated articles in competition with light metals. Much of the molecular technology with ABS base copolymers and its alloys is highly empirical with specialized grades and forms for specific articles. It can be expected that innovations or advances in base polymers and alloy formulations will display significant growth in the next decade. Particularly significant, it can prudently be predicted, is the promising future of the ABS/PVC alloys by virtue of the self-extinguishing characteristics that is assuming ever-increasing importance especially with the increasing penetration of plastics into housing and construction.

IV. REINFORCED, FILLED COMPOSTIONS

From the outset of plastics technology, such as that initiated by the thermosets, the use of fillers of various sources and types has been useful in providing a broad range of reinforcement from the standpoint of mechanical endurance and especially stiffening the plastics artifact. In more recent times, the fillers have been accorded special study with regard to the interface to the polymer substrate, a case in point being that of the use of treated glass fibers to enhance the bonding between the filler and the plastics matrix, a feature made subject of much experimental and theoretical studies (11). The conventional use of fillers as extenders, which often served to reduce the deformation under compressive load as is the case of vinyl flooring, has been extended by the now expanding glass fiber and filament reinforcing with thermoset resins on the one hand and by the incorporation of chopped fibers and filaments into moulding stock for extrusion and especially injection moulding technology. Composites of plastics with inorganic fibers are now taking on a significant segment of the plastics applications, across practically all of the principal types of chemical polymers including the specialty, high-temperature polymers.

The advance in the annual development and utilization of reinforced thermoplastics (12), from an emerging technology in 1955, attained a level of 5 million pounds (2.28 million kilos) by 1965 and by 1971 surged to a level of 74 million

pounds (3.37 million kilos). First introduced as a specialty plastic, the glass fiber filled plastics attained its present level by virtue of increased penetration into the automotive and appliance industries. The distribution of the usage using the U.S.A. data as a bell-weather of the trends is depicted in Table 6, indicating that the largest segment would reside in the polyolefin reinforcement and that this is where the technological emphasis should be placed for developing economy. It is however recognized that reinforced polyesters are expected to display a significant growth and that reinforced structural foams will also develop a significant volume level in the next few years. As was predicated by the past historical development of the reinforced plastics, the progress in the expanded utilization resulted to a large measure from development of some unique combination of two or more properties resulting from the incorporation of the filler. Typical of these reinforcement is listed in Table 7 for a selected variety of mechanical properties and with representative polymers, based on the more or less conventional, standard glass fibers.

Apart from the well-established glass fiber type of reinforcement, a marked trend is appearing in the adoption of other fibrous reinforcing fillers notably carbon and graphite fibers, metal and ceramic whiskers, and synthetic fiber yarns.

Carbon and Graphite Fibers. With the corollary development of continuous processes for making strong, uniform carbon yarn, notably from rayon and polyacrylonitrile, the usage of these fibers has been directed toward fiber-plastics composites in

the aerospace industry primarily because of the weight advantage of these composites. Spin-off applications from the aerospace applications are finding some interest in special high-temperature frictional and sealing applications.

Metal and Ceramic Whiskers. Endowed with exceptionally high stiffness attributes, this groups of reinforcing fillers are for economic reasons relegated to extremely specialized applications especially where thermal endurance in combination with retained stiffness over prolonged periods of exposure have to be specified. Expensive by virtue of the costly methods of obtaining the single crystal or whisker structure, this class of fillers has produced a wealth of information in regard to alignment and bonding of the filler to the plastic matrix. An early venture into less expensive acicular fillers has been recently inaugurated with titanates (13) that proffer some interesting opportunities to enhance the properties of the well-established oldline plastics, primarily on the basis of (a) extension of the glass fiber dimensions to that more nearly proximal to the fine structure of crystalline and semicrystalline polymers, (b) controlled alignment of the properties of the reinforced composition by virtue of the directed acicularity of the fibers, and (c) providing lower order of moisture absorption than that of the glass or silicate type fillers. More importantly, the inorganic fillers show distinct merits not only in increased tensile properties but also in reducing the thermal coefficient of expansion to that of the light metals.

V. CONCLUSIONS AND RECOMMENDATIONS

From the foregoing discussion of the advances in plastics technology and commerce, it is indicated that technical advances in both the polymer innovations and fabrication engineering to provide increasing range of plastics articles can be expected to accord old-line established polymers with a significant growth potential. It is prudent and necessary to view the polymer structure even with established monomers as one that is not only fixed in the usual sense as a manufactured resin going directly to the fabrication machinery, but also labile and reactive in the fabrication operation to produce new molecular variations even though the basic chemical units of the monomers are substantially the same. It is now evident that a much closer coordination of specified construct - fabrication technology - polymer variations as a continuum in the chain of development through adjustments in molecular architecture is proving quite fruitful, judging from one segment of a national production and consumption of plastics. The definition of what now constitutes a new polymer takes on a new meaning that considers not only the molecular architecture but also the adjuvants that become important to fulfill such diverse needs as making large constructs such as tanks, on the one hand, and degradable polymers to obviate ecological problems on the other.

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TABLE 1. GROWTH OF THERMOSET PLASTICS PRODUCTION
(U.S.A. - 1972)

PLASTICS TYPE	PRODUCTION		ANNUAL GROWTH	
	1000 METRIC TONS		PERCENT	
	1966	1971	1966-71	1972 (a)
Phenolics	475.8	542.6	3	22
Urea-melamine	346.5	365.0	2	18
Polyester	213.7	332.0	9	33
Epoxy	63.6	75.0	3	9
TOTAL	1079.6	1314.6	4	23

(a) Comparison between first-half 1972 and first-half 1971
Source: U. S. Tariff Commission; Society of Plastics Industry; Chem. and Eng. News, Sept. 11, 1972, page 11.

TABLE 2. GROWTH OF THERMOPLASTICS PRODUCTION - U.S.A.

POLYMER TYPE	PRODUCTION 1000 METRIC TONS	FIRST-HALF 1972 GAIN OVER FIRST HALF 1971
POLYETHYLENE		
LOW DENSITY	1,159	18 %
HIGH DENSITY	495	25
POLYPROPYLENE	364	37
POLYSTYRENE (a)	686	27
POLYVINYL CHLORIDE	927	24
TOTAL	3,631	24

(a) STRAIGHT AND RUBBER-MODIFIED

SOURCE: Society of Plastics Industry (U.S.A.); Chem.
and Eng. News, Aug. 28, 1972, page 8.

TABLE 3. THERMOPLASTICS OUTPUT - U.S.A. 1972 vs 1971
(1000 METRIC TONS PER ANNUM)

	PRODUCTION		CAPACITY		UTILIZATION	
	1971	1972	1971	1972	1971	1972
POLYETHYLENE						
LOW DENSITY	2045	2328	2228	2500	91%	93%
HIGH DENSITY	882	1051	955	1113	92	95
POLYPROPYLENE	573	746	750	800	76	93
POLYSTYRENE (a)	1160	141	1455	1636	80	86
POLYVINYL CHLORIDE	1564	1878	1818	1909	86	98
TOTAL	6224	8144	7204	7958	86	93

(a) Straight and rubber-modified polystyrene

Source: Society of Plastics Industry; Chemical and Engineering News, August 28, 1972, page 8.

TABLE 4. PROPERTIES OF CROSSLINKED POLYETHYLENE (PE) TYPES

PE TYPE (MOL.WT.)		MEDIUM		HIGH		LOW	
NON-	X-LINKED*		*		*		*
TENSILE YIELD		110	95	300	190		165
(kp/cm ²)			250		(200)		(180)
TENSILE STRENGTH		150	250	390	170		150
(kp/cm ²)					(180)		(140)
ELONGATION		500	700	800	150		105
(percent)					(150)		(95)
MODULUS				11500	3500		
(kp/cm ²)					(3500)		
SOLUBILITY (%)		100	6	100	1	100	6
(Toluene)					(2)		(7)
SWELLING (%)			300		200		250
(Toluene)					(300)		(300)

TABLE 5. SELECTED PROPERTIES OF ABS MOULDING ALLOYS

PROPERTIES	UNITS	ABS/PVC	ABS/PVC	ABS/PU	ABS/PU
		Rigid	Flexible	Rigid	Rigid
TENSILE STRENGTH	kp/sq.cm.	383	219	236	576
TENSILE MODULUS	10^4 kp/sq.cm.	22.5	7.0	15.5	25.9
IZOD IMPACT, NOTCHED	(Ft.lb/in)	12.5	15.0	8.0	10.3
HARDNESS, ROCKWELL		102R	55R	82R	118R
HEAT DISTORTION	$^{\circ}$ C.	71.5	90.5	97.0	127.0
SPECIFIC GRAVITY		1.21	1.13	1.04	1.24

TABLE 6. USAGE OF FIBER GLASS REINFORCED THERMOPLASTICS
(U.S.A. 1971 ESTIMATES)

	1000 METRIC TONS	PERCENT
POLYETHYLENE)	13.4	40
POLYPROPYLENE)		
POLYSTYRENE (a)	11.1	33
NYLON	4.0	12
POLYCARBONATE)	5.1	15
OTHERS)		
TOTAL	33.6	100

(a) Straight and rubber-modified.

TABLE 7. TYPICAL MECHANICAL PROPERTIES OF REINFORCED THERMOPLASTICS (30% GLASS FIBERS)

PROPERTY	POLY- PROPYLENE	POLY- STYRENE	NYLON	POLY- CARBONATE
TENSILE STRENGTH (Kp/cm ²)	(281) 562	(281) 1025	(633) 1758	(633) 1334
FLEXURAL MODULUS (Kp/cm ²)	(14060) 42180	(28120) 84360	(21090) 70300	(21090) 147630
IMPACT STRENGTH (Qualitative)	(V.GOOD) GOOD	(POOR) PAIR	(V.GOOD) V.GOOD	(V.GOOD) V.GOOD
TEMPERATURE DISTORTION (°C.)	(54.5) 132.8	(82.0) 104.5	(71.5) 146.0	(132.0) 143.0

*() Values refer to unfilled controls, parent plastics.

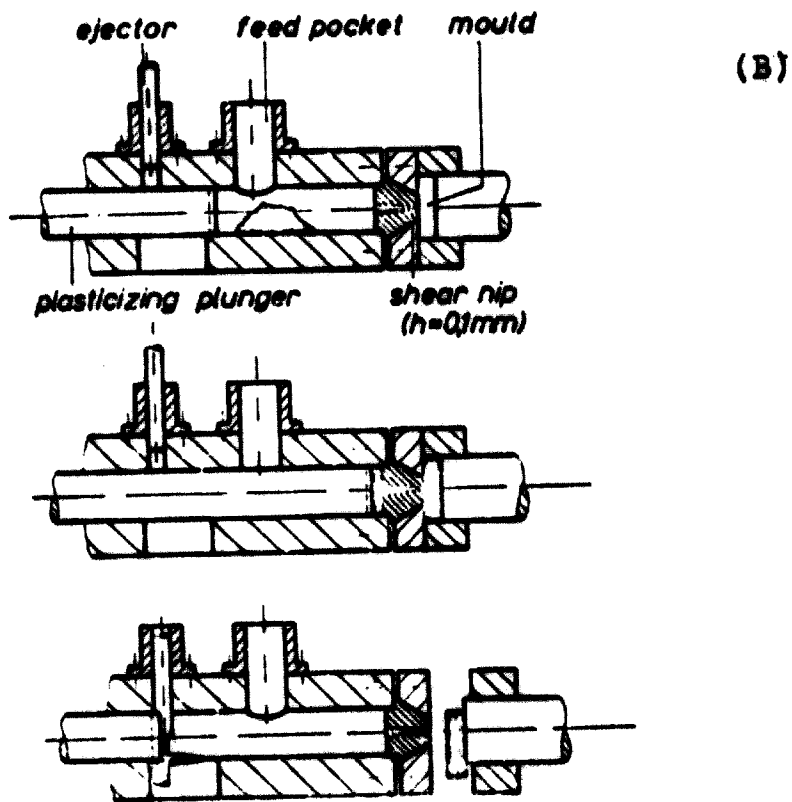
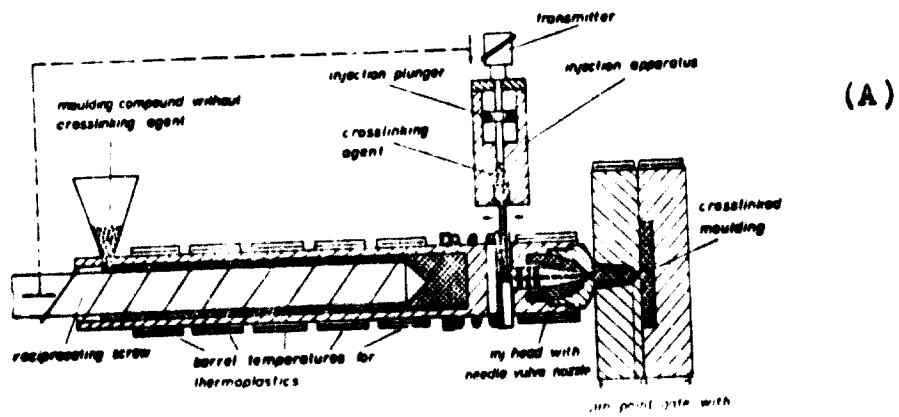


FIGURE 1. INJECTION MOULDING SYSTEMS
(A) MIXING FOR CROSS-LINKING AGENTS
(B) MOULDING WITH ULTRA HIGH PRESSURES

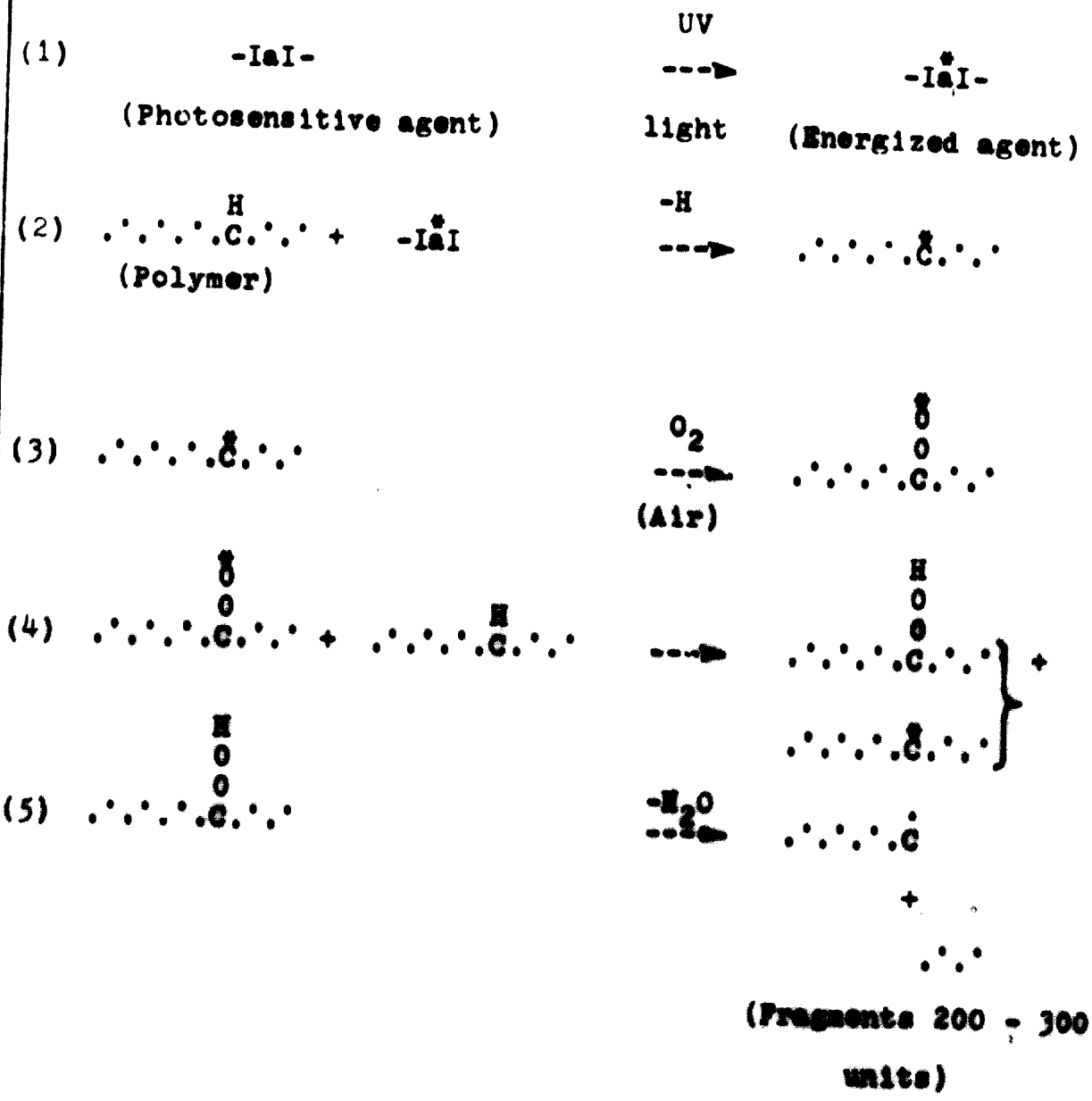
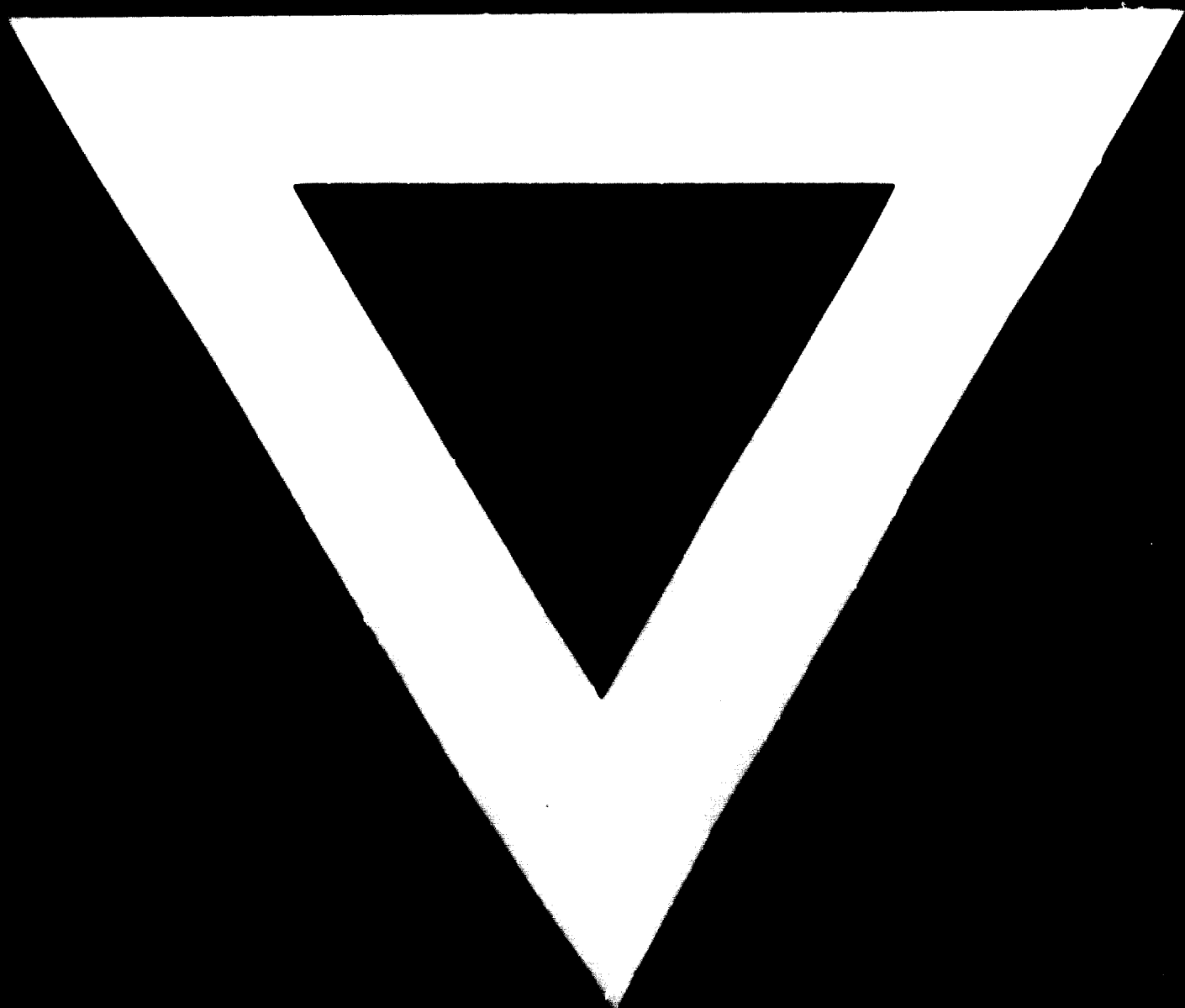


FIGURE 2. MECHANISM OF POLYMER BREAK-DOWN BY PHOTODEGRADATION



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