New Trends in Industrial Polymer Research

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Summary: In the past decades a shift in paradigm took place in industrial polymer research. Only a few new polymers were developed based on new monomeric building blocks. The main focus is now on tailoring "new polymers" with well-defined structure and properties based on a set of low cost "old" monomers using controlled polymerization mechanisms.

Keywords: mechanical properties; thermoplastics

Some one hundred years after they were first synthesized industrially, and eighty years after their molecular structure was solved, synthetic polymers continue to play an important role as structural, functional and special-effect materials, satisfying the material needs of today´s society in the areas of diet and nutrition, health, accommodation, clothing, communication and mobility. The demand for structural and functional polymers has grown over the last one hundred years to generate a current world market volume of 200 million metric tons. The secret of the success of structural polymers is to be found in their unique combination of hardness, lightness, resistance to corrosion, flame-retardant properties, weathering resistance, rigidity and toughness. Functional synthetic polymers offer a wealth of physical properties that find use in a huge range of applications and which today include such characteristics as electrical conductivity and electro-luminescence. In terms of production volume (in m^3), structural synthetic polymers have overtaken steel in the last twenty years (Figure 1).

A comparison of national consumption levels shows that the per capita demand for synthetic polymers essentially mirrors the growth in the gross domestic product (Figure 2). The consumption of synthetic polymers can thus be taken as a measure of how advanced an economy is.

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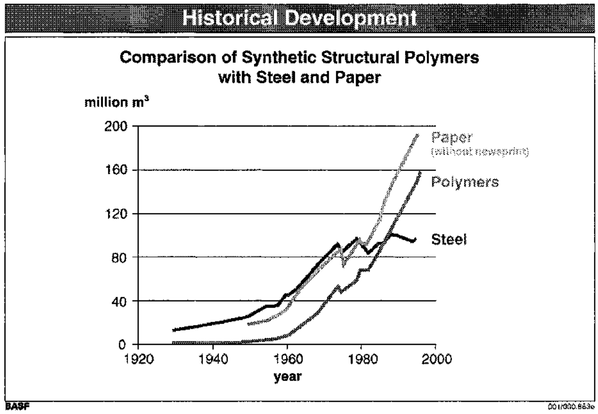

Figure 1. The historical development of synthetic structural polymers compared to steel and paper.

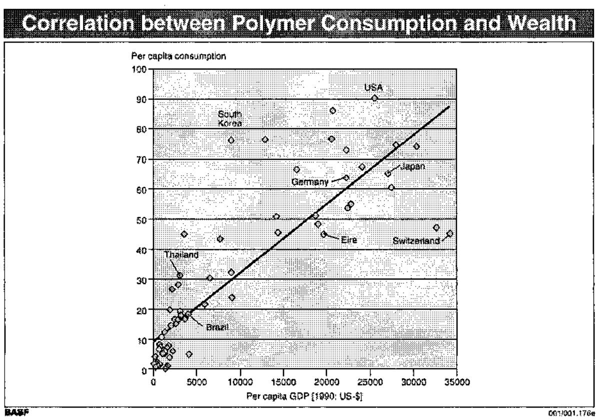

Figure 2. The correlation between polymer consumption and wealth.

Just as natural polymers such as proteins and DNA are essential for life, synthetic polymers are indispensable in maintaining our current standard of living.

Many of the commercially most important classes of polymers were first manufactured industrially decades ago. Polystyrene (PS) and PVC both 70 years ago, polyethylene (PE) 60 years ago. Only a few commercially relevant polymer classes have been introduced within the last 40 years. In terms of volume, the four largest classes of synthetic polymers (Polyethylene, Polypropylene, PVC and Polystyrene) make up over 80% of the world market, as they did 20 years ago (Figure 3).

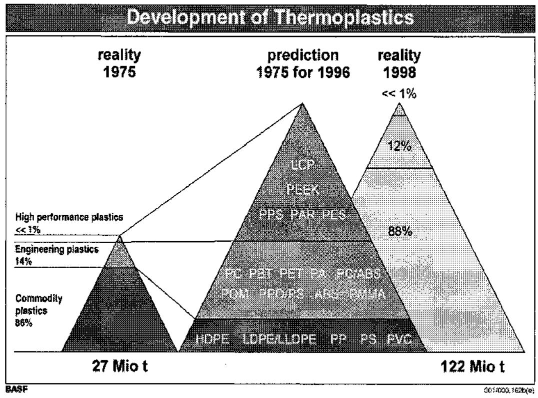

Figure 3. The development of thermoplastics within the last 25 years.

The synthetic strategies exploited for manufacturing macromolecules industrially i.e. polymerization, polycondensation and polyaddition have been in use since the first half of the last century. The question thus arises as to whether the science of synthesizing industrial polymers and their properties is a mature technological area and whether the industrial use of these materials is a part of the "old economy" and therefore an area of little promise for the future. Would the considerable sums spent on academic and industrial research into synthetic polymers be better invested in other research activities?

The answer is quite clearly "no". And nature shows us why. Nature synthesizes polymeric materials, fibers and highly functionalized polymers such as enzymes or receptors from a limited number of components, the 20 amino acids, and demonstrates how the sequence of these components determines the three-dimensional shape of the macromolecules themselves and their higher order assemblies. In analogous fashion, it should be possible to use a limited set of about 30 to 40 different monomers, which can be produced cost-effectively in large-scale industrial plants, to manufacture synthetic polymers with wholly new or significantly improved property profiles if we can succeed in building up macromolecules by sequencing the monomers in a predictable and controllable manner. This set of basic components includes non-polar monomers such as ethylene and styrene, monomers like acrylic acid that lead to water-soluble polymers, monomers like butadiene which produce polymers which are soft at room temperature and monomers such as styrene which are used to make polymers that are hard and brittle at room temperature.

The theoretically achievable range of property profiles is still a long way from being exhausted. If the modulus of elasticity – an important mechanical property – of various materials is compared, one finds that the theoretically obtainable values have long been reached in the case of classical materials such as steel or glass. However, in the case of thermoplastics such as polyamide 6 or polyethylene, the elasticity modulus of molded parts is only a few percent of that which is theoretically possible. While this is not saying that the theoretical values can in fact be achieved, the discrepancy between the theoretical and current measured values is so great that there is certainly room for significant improvements (Figure 4).

Comparison of Different Materials

Material	Elasticity modulus [MPa]		
	theoretical	experimental	
		Fiber	Plastics
PP	50 000	20 000	2 000
PA66	160 000	5 000	3 200
Glass	80 000	80 000	70 000
Steel	210 000	210 000	210 000

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Figure 4. Comparison of mechanical properties of different materials.

Major progress will be driven by developments in basic and applied research in the fields of polymer chemistry, polymer physics and material science. In particular by:

An improved understanding of the relationship between primary and higher-order structures of synthetic macromolecules and the desired physical and applications-related material properties; Developing effective methods of achieving the controlled polymerization of a large number of monomers to create macromolecules with specially tailored structures. Related to this is the development of catalysts of even higher selectivity and even greater efficiency.

Exploiting the methods of high-throughput synthesis, high-throughput screening and data management will also significantly accelerate research in these areas.

Considerable progress has been made in the last twenty years and the field remains a highly attractive one to those involved in university level research. The results from basic research programs carried out in university departments and research institute have been rapidly scrutinized for their industrial applicability and the promising results have frequently been implemented. One of many examples is the use of metallocenes to catalyze the polymerization of olefins. This development has meant that the prediction, made 25 years ago, which stated the commodity polymers polyethylene, polypropylene, polyvinyl chloride and polystyrene would be squeezed out of the market by other polymers with considerably improved properties, engineering plastics and other high-performance polymers, has not been confirmed. By carefully tailoring the manufacture of standard polymers it proved possible to improve the material properties to such an extent that commodity plastics began to occupy areas that were previously the domain of engineering plastics. While the polypropylene of 25 years ago and the polypropylene of 2002 have the same name and are made of the same components, today's product is a different, considerably improved material. Of course, the engineering plastics sector has also seen considerable growth, with polycarbonate for example showing growth rates of well above 10% per annum.

Fundamental research aimed at discovering new polymers with novel properties based on radically new monomeric species remains, naturally enough, an attractive objective to those involved in basic research. However, the practical use of these materials will tend to be found in niche markets. The problem with many of the new functional polymers, no matter how interesting they may be from an a scientific point of view like the electroconductive polymers, is that they are almost predestined to achieve global sales volume of less than US$ 50 million. In most cases these functional polymers represent only a small percentage of the value of the end product (Figure 5).

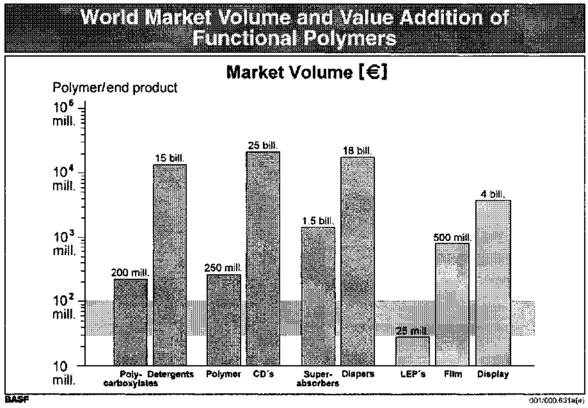

Figure 5. World market volume and volume addition of functional polymers.

For a major polymer producer, sales at that sort of level are of little interest when compared to the multibillion $ total polymer sales, and marketing such products can do little to secure the future overall success of the business with polymers. In this case what is needed are cooperative ventures between the polymer-producer and the value-adding polymer-processing companies at all stages of the value chain based on a fair distribution of the added value. Under such circumstances, the development and marketing of such polymers can become attractive even for major polymer producing companies.

Without polymers, there would be no car, no space station, no TV, no laptop and no DVD. The high double-digit growth rates of a polymer such as polycarbonate are impressive proof of this. The products of the information technology age, the much lauded "new economy" are inconceivable without synthetic polymers.

Synthetic polymers are not products of the "old economy", but are rather the highly sought-after products of a "classical" or perhaps more appropriate a "classy" economy.