MECHANICAL WORKING OF MATERIALS

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Summary

One of the key factors contributing to the development of civilisation has been the abundant supply of materials provided by nature. Throughout history it has been recognised that if we are to survive and prosper, these materials must be converted into useful artefacts. In the early days, readily available materials such as wood, skins, shells and resins were employed for houses, weapons, eating utensils and modes of transportation. The manufacturing methods were ingenious but basic, involving operations such as cutting, forging and casting. As time progressed, less readily available natural materials, such as ores, were converted into metals and these then went through a secondary mechanical working stage to be turned into something useful. Eventually we became sufficiently familiar with the basic structure of materials to enable synthetic materials to be created and, as a result, a whole new range of manufacturing methods evolved to make products that could hardly have been imagined 100 years ago.

The manufacturing technologies that are available today are wide ranging. The method chosen for a particular application will depend on many factors - the material being formed, the shape of the end-product, the market size, etc. And the methods available are continually increasing in number as new types of market demands mean that new

manufacturing methods have to be developed to meet special needs. Many of these new methods are hybrids of existing methods and they enable new shapes to be created with unique functionality or more attractive economics.

Most metal products are manufactured by well-established methods such as machining, casting, pressing and drilling. The use of these methods has been well documented and whilst there have been steady improvements there have been few major innovations in these sectors. This article looks at the manufacturing methods that are available primarily for plastics since these tend to be the most exciting and creative. Indeed nowadays many of these methods are being adapted for use with metals and ceramics due to the opportunities that they present for high volume manufacture of complex shapes at attractive costs. In some cases the pendulum has swung back to its start position in that many of the original plastics moulding methods evolved from metal die casting or blow moulding of bottles. The plastics industry has taken these technologies and developed them into high speed, high volume manufacturing methods that offer major advantages to all types of materials.

1. Introduction

If you ask why plastics are so widely used today, the answers received will almost inevitably refer to their relatively low cost or their lightness or their ready availability in many colours. Whilst these are important factors, there are few applications where they would be sufficient justification for using plastics. For example, in the automotive industry, where weight saving is a commendable objective to save energy, it has been estimated that for every 100 kg saved by using plastic, the fuel saving during the lifetime of a family car is about 750 litres. This is relatively small in terms of the total fuel bill over the life of a car and it is debatable if it is worth all the design effort of making the switch to plastic, particularly as any new application for plastic in cars is likely to be a small fraction of the 100 kg saving.

In fact the main rationale for using more and more plastics in cars, and in most other application areas, is the ease with which they can be shaped into useful products. The big advantage that plastics possess is that they can be mechanically formed into complex shapes at very high speed at relatively low temperatures. This means that manufacturing costs are low, which is key requirement in any successful business. Thus the contributions to energy savings are more likely to come from the lower fuel bill at the manufacturing stage than at the end-user stage. The additional attributes of lightness, colour fastness, flexibility, chemical resistance, electrical insulation and so on, are bonus factors that are to be welcomed and can be put to good use in specific applications.

2. Types of Plastic - Effects on Manufacturing Methods

Polymers are a class of materials in which small molecular units ("mers") are joined together in a chemical process to create long chain-like molecules (see Structure and Properties of Polymers). Such materials are available in nature - resins from plants, skin and human nails- but it is the synthetic polymeric materials, often referred to as plastics that are of interest in this article. The unique structure of polymers has an influence on the manufacturing methods used for these materials and the inter-relationships between processing conditions and the morphology of theses materials can affect, in a positive or negative way, the properties of the moulded part. It should be pointed out that although the words "polymer" and "plastic" are often used to mean the same thing, strictly speaking the polymer is the pure chemical substance created by the chemical reaction referred to above. In most cases the pure polymer has no commercial value on its own and it only becomes a useful material - the plastic - when it is combined with additives to make it thermally stable, to protect it from ultra-violet light, to improve its flow behaviour, etc.

In the context of manufacturing methodologies, it is important to recognise the differences between the main classes of polymers. *Thermoplastics* are the easiest to work with and are the more common materials - representing over three-quarters of all the plastics in everyday use. These materials soften when heated and are easy to work mechanically into a complex shape that is retained when the material is cooled. An advantage from the manufacturing point of view is that the material can be re-worked if it is re-heated and softened again. Of course this characteristic is not attractive in service where the thermoplastic loses its shape if it becomes hot in service.

The other main class of plastic is the *thermoset*. This material is in a semi-finished state when it is supplied to the moulder. During the manufacturing stage, the application of heat and pressure to create the desired shape initiates an irreversible chemical change in the material. The structure of the thermoset becomes locked into a three dimensional network, referred to as "cross-linking", which causes it to become solid. This makes manufacturing more problematic because the part must be right first time. There is no second chance to re-soften the material by heat if the shape produced is not what was intended. Of course this is a feature which is attractive to the end-user because the material is well suited to high temperature applications or situations where the part might become hot accidentally, e.g. electrical switches or saucepan handles.

Originally the manufacturing methods that evolved for these two classes of materials were separate and distinct. Thermosets favoured simple moulding technologies such as compression moulding in which there was easy access to all parts of the moulding equipment if the plastic became solid prematurely. Thermoplastics on the other hand had the advantage of being amenable to a very wide range of moulding methods, such as thermoforming, injection moulding, extrusion, blow moulding and so on. Their user-friendly moulding behaviour was to a large extent the reason why they came to dominate the marketplace in applications where either type of material could have been used on the basis of their mechanical properties.

Nowadays the distinction between the processing methods for the two types of material is less clear. As will be seen in the following sections, the sophistication and preciseness of process control is now at the point where thermosets can be extruded, and injection moulded on equipment very similar to that used for thermoplastics. They can therefore reap the benefits of faster production methods whilst retaining the advantage of offering high temperature and more consistent properties to the end user. Thermoplastic materials have also moved into thermoset manufacturing sectors in order to reap the benefits of better economic at lower production volumes and, in particular, the opportunity to combine reinforcing fibres with thermoplastics in ways that are difficult using conventional moulding methods. Methods are also available to initiate cross-linking reactions in thermoplastics as they are being moulded, to impart better mechanical properties in the end-product.

There are other types of polymers, the nature of which can affect the mechanical working used to create useful artefacts. Examples are *elastomers*, which exhibit the high elasticity of rubbers but the ease of manufacture of thermoplastics. Also, some polymers lend themselves to polymerisation (conversion of the mers into long chains) during moulding. This has the advantage that the base chemicals that combine to make the polymer can be injected simultaneously into a mould to create the polymer and the moulded article at the same time. As the base chemicals often have a significantly lower viscosity than the polymer, they flow more easily in the mould and so much larger articles can be created using less forces and therefore smaller moulding machines.

3. Manufacturing Methods for Plastic Parts

A major advantage of plastics is the wide range of moulding methods that are available. Almost any shape can be created in a large number of materials. However, not all shapes can be created by all manufacturing methods and not all plastics lend themselves to each manufacturing method. For example, it is difficult to thermoform the highly crystalline plastics because at lower temperatures they are too stiff and then they melt rapidly to a low viscosity melt over a narrow temperature range. Many plastics cannot be rotationally moulded because they would degrade at the high temperatures applied over a prolonged period of time. The shape constraints on the various moulding methods are less severe than they once were. At one time it was not possible to injection mould hollow items in one piece. However, market demands for products of this type led to the development of lost core injection moulding technology. There are other similar developments in many areas of moulding, not just for plastics but also for ceramics and metals. This is what makes it a dynamic, challenging and exciting industry. In many cases the researchers, the designers, the moulders and the end-users are working closely together to take maximum advantage of the materials that are available to us. The following sections review the various moulding methods that are available and discuss the future innovations that are likely.

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Biographical Sketch

Professor Roy Crawford obtained a first-class honours degree in Mechanical Engineering from The Queen's University of Belfast in 1970. He went on to obtain PhD and DSc degrees for research work on plastics. Over the past 30 years he has concentrated on investigations of the processing behaviour and mechanical properties of plastics. He has published over 250 papers in learned journals and conferences during this time. He has also been invited to give keynote addresses at conferences all over the world. He is the author of 5 textbooks on plastics and engineering materials.

Roy Crawford is currently Professor of Mechanical Engineering at the Queen's University of Belfast. He is a Fellow of the Institution of Mechanical Engineers and a Fellow of the Institute of Materials. In 1997 he was elected as a Fellow of the Royal Academy of Engineering. He has been awarded a number of prizes for his research work, such as the prestigious Netlon Medal from the Institute of Materials for innovative contributions to the moulding of plastics.