Metal parts from microwaves

Microwave sintering is proving to be a viable method of producing metallic parts, as Dinesh Agrawal explains.

Microwave energy has been in use for a variety of applications for over 50 years. Some of the early applications include communication, navigation and drying of food items. At present, industrial uses of microwaves include wood processing, vulcanisation of rubber, meat tempering, and medical therapy. In the past two decades, the remarkable success of domestic microwave ovens has revolutionised home cooking.

The use of microwaves in ceramic processing is a relatively recent development - they can be applied effectively and efficiently to heat and sinter ceramic objects. The most recent development in microwave applications is in sintering of metal powders - a surprising application, in view of the fact that bulk metals reflect microwaves. However, we have found that reflection by a metal occurs only if it is in a solid, nonporous form and is exposed to microwaves at room temperature. Metal in the form of powder will absorb microwaves at room temperature and will be heated very effectively and rapidly.

We are now using this technology to sinter various powder metal components, and are producing useful products ranging from small cylinders, rods, gears and automotive components in 30-90 min.

Microwave heating and sintering is fundamentally different from the conventional sintering, which involves radiant/resistance heating followed by transfer of thermal energy via conduction to the inside of the body being processed. Microwave heating is a volumetric heating involving conversion of electromagnetic energy into thermal energy, which is instantaneous, rapid and highly efficient.

The microwave part of the electromagnetic spectrum corresponds to frequencies between 300 MHz and 300 GHz. However, most research and industrial activities involve microwaves only at 2.45 GHz and 915 MHz frequencies. Based on their microwave interaction, most materials can be classified into one of three categories - opaque, transparent and absorbers. Bulk metals are opaque to microwave and are good reflectors - this property is used in radar detection. However, powdered metals are very good absorbers of microwaves and heat up effectively, with heating rates as high as 100 °C min⁻¹. Most other materials are either transparent or absorb microwaves to varying degrees at ambient temperature. The degree of microwave absorption, and consequently of heating, changes dramatically with the temperature.

The use of microwave energy for materials processing has major potential, and real advantages over conventional heating. These include time and energy savings, rapid heating rates, considerably reduced processing time and temperature, fine microstructures and hence improved mechanical properties, better product performance, and lower environmental impact.

Until recently, microwave heating has been applied to sinter only oxide ceramics and semimetals like carbides and nitrides. However, our research reveals that in powdered form, virtually all metals, alloys, and intermetallics will couple and heat efficiently and effectively in a microwave field, and their green parts will produce highly sintered bodies with improved mechanical properties. For example, in our exploratory experiments we tried two common commercial steel compositions, namely Fe-Ni-C (FN208) and Fe-Cu-C (FC208). These formed highly sintered bodies in a total cycle time of about 90 min at temperature range of 1100–1300 °C with a soaking time of 5–30 min in forming gas (a mixture of N₂ and H₂) atmosphere. Mechanical properties such as the modulus of rupture (MOR) and hardness of microwave processed samples were significantly higher than the conventional samples - in the case of FN208, the MOR was 60% higher. The densities of microwave processed samples were close to the theoretical densities, and the net shape of the green body was preserved without significant dimensional changes.

Many commercial powder-metal components of various alloy compositions, including iron and steel, copper, aluminum, nickel, molybdenum,
Weighing up her future

Since winning the Young Engineers for Britain title in September, 18 year old Michelle Dagnall has decided to rethink the prospect of reading history at university and is devoting some of her time and prize money, to making a successful business venture from her innovative idea. Michelle's award-winning invention 'Safe-weigh' - an ingenious new device that could dramatically reduce the number of road accidents involving caravans and trailers - picked up The Institute of Materials prize for best use of materials as well as the overall title at the competition final held in London's Commonwealth Institute.

With such success under her belt, Michelle is looking to maximise the publicity she has gained for her A-level project at Eckington School, Sheffield, and turn it into a successful venture. As Eckington School was one of the 100s first school affiliates, the Institute's Professional Policy Board has been working with Michelle to help produce a business plan by offering her advice and suggestions on how to develop her project.

The idea for Michelle's A-level project came about after her father experienced difficulties with his caravan when trying to measure the 'noseweight' of his trailer. When loading a caravan it is important to make sure that the noseweight - the static downward pressure of the caravan's A-frame on the car's tow ball - is within legal limits. Exceeding these weight limits can cause problems for drivers in manoeuvring and controlling their vehicles.

Michelle found that a large number of accidents involving caravans and trailers occurred because of people wrongly loading their towed vehicle and often unknowingly exceeding the legal limits for noseweight. This can cause the caravan to sway and shake until the driver loses control,' says Michelle. Examining the market for weighing devices in this area, Michelle found that the portable weighing devices currently available are difficult to use and frequently topple over. To avoid these problems, Michelle came up with the idea of fitting a spring-loaded gauge directly into the structure surrounding the trailer or caravan's jockey wheel. This, Michelle says, makes her device extremely easy to use and is also much safer as the owner does not have to try and balance the caravan on any portable devices.

Michelle built the gauge using specially constructed steel springs made by a local company. A spring, once heated in a stress-relieving machine to 300-350°C, is fitted into an oval steel casing with an easy-to-read gauge on the side. Michelle's simple device has been designed to weigh caravans with a noseweight of 45-110kgs.

Michelle calculates that it will cost £29.26 to build one of her devices in batches of 500. She has a patent pending on the device and is confident that her 'Safe-weigh' project will become a commercially viable product. 'With all of the publicity that the Young Engineers competition has brought, I think that there is a good chance that someone will pick up on my project,' she says. Michelle will also find her £4,500 prize money more than useful in starting her university career and launching her product.

The competition final brought together more than 50 young engineers who had won through from 13 regional finals staged throughout the UK. Glenda Jackson MP, presenting the awards, said, 'I have sheer admiration for the talent of these young individuals.' Other successful finalists included Darren Fenton from Grosvenor Grammar School in Belfast. Darren has designed and built a multi-functional torch that could be used by police to safely control traffic without putting themselves, or motorists, at risk. The current system uses a red plastic cone fitted on top of a regulation police torch. The cone can often lead to confusion for motorists as the waved signals for 'come' or 'stay' often look similar on a dreary evening. Darren's device features a green signal for 'come' and a red signal for 'stay' and it can also be used as a regular torch. Darren designed and built his prototype model, made from polycarbonate plastic with help from Short Brothers Ltd in Belfast, to be powered by the same battery used for speed guns. The traffic control torch has aroused great interest from police forces throughout the UK who are interested in replacing the current device that has led indirectly to a number of accidents involving police officers. The torch is undergoing trials and if successful could soon be helping the police keep traffic safely under control.

The winner of the Young Engineers for Britain competition is finding a business ally in the Professional Policy Board of The Institute of Materials. Michelle Dagnall is discovering what life is like turning a school project into a successful business venture, reports Andrew McLaughlin.
cobalt, tungsten, tungsten carbide, tin, and their alloys have been sintered using microwaves, producing essentially fully dense bodies. Figure 1 illustrates some of the metallurgical parts processed using microwave technology. The biggest commercial steel component that has been fully sintered in our system so far is an automotive rear of 10 cm in diameter and about 2.5 cm in height.

A typical microwave sintering apparatus operates at a 2.45 GHz frequency with power output in the range of 1-6 kW. The sintering chamber consists of ceramic insulation housing (batch system) or an alumina tube insulated with ceramic insulation from outside, figure 2. The primary function of the insulation is to preserve the heat generated in the workpiece. The temperatures are monitored by optical pyrometers, IR sensors and/or sheathed thermocouples placed close to the surface of the sample. The system is equipped with appropriate equipment to provide the desired sintering atmosphere, such as \( \text{H}_2, \text{N}_2, \text{Ar} \), etc., and is capable of achieving temperatures up to 1600 °C.

The technology can be easily commercialized by scaling up the existing microwave system or designing a continuous system capable of sintering parts of various shapes and sizes. We have already initiated several steps in this direction and hopefully, our new technology will be soon manufacturing metal parts for various applications.

The implications of microwave sintering of metals are obvious in the field of powder metal technology. Metal powders are used in a diverse range of products and applications in various industries, including the automotive industry, aerospace, and savvymachinery. The challenging demands for new and improved processes and materials of high integrity for advanced engineering applications require innovation and new technologies. Finer microstructures and near-theoretical densities in special powder metal components are still elusive and widely desired. Increasing cost is also a concern of the industry. Microwave processing offers a new method to meet these demands of producing fine microstructures and better properties, and potentially at lower cost.

There are two main reasons why the microwave process yields better mechanical properties, especially in the case of powder metals—it produces a finer grain size, and the shape of the porosity, if any, is quite different than in a conventional part. In microwave-processed powder metal components, we have observed round-edged porosities producing higher ductility and toughness.

So far, there has been little effort devoted to understanding the mechanisms and the science behind microwave sintering of metals. However, it is obvious that the microwave-metal interactions are more complex than those working actively in the field had expected. There are many factors that contribute significantly to the total microwave heating of powdered metals. The sample size and shape, the distribution of the microwave energy inside the cavity, and the magnetic field of the electromagnetic radiation are all important in the heating and sintering of powder metals. This research is just at the early stages, and it will be a long time before the exact mechanisms are elucidated.

Further reading

Foresighted is fore-armed for powder metallurgy

Although a global force, the UK powder metallurgy (PM) industry is facing a variety of challenges – global sourcing, supply chain restructuring, environmental legislation affecting life cycle design, etc. Research into this area lacks coordination, as do initiatives related to education and training.

Between November 1998 and March 1999 the UK Chapter of EPMA carried out a Foresight review of the PM industry, in conjunction with the British Hardmetals Association and the UK Magnetics Society and with support from the DTL. The Foresight analysis covered ferrous structural parts, hardmetals, and hard magnets. Its overall objectives were:

- to identify areas of weakness in the UK PM sector affecting its global competitiveness, and ensure that appropriate investment be made to achieve continuous improvement
- to improve management awareness of new materials and emerging technologies such as metal injection moulding and hot isostatic pressing
- to improve interaction between industry and RTOs, and among the trade associations serving the different sectors of PM
- to ensure that the industry takes full account of its effect on the environment, and on human wellbeing.

During the consultation process, all parts of the supply chain were approached, as well as certain university departments, interest groups, and associations and institutions. Other key contacts were made with the HSE and the DETR. The consultation community was addressed in a variety of ways, including questionnaires, structured panel discussion, face-to-face or telephone interviews, and at a later stage, a workshop.

From the conclusions reached, various recommendations have been made for all three PM sectors and for the specific areas surveyed. Recommendations common to all sectors are:

- trade associations should take up education issues in collaboration with PM companies, universities, professional institutions and learned societies. They should provide awareness of environment issues to companies, consider collaboration on environmental issues at national and European level, and discuss professional training for engineers with The Institute of Materials.
- centres of excellence should be identified and R&D priorities and funding determined.
- markets that fit the technology should be identified instead of searching in familiar sectors.
- niche/specialised markets should be identified, and PM companies should set up in-house facilities to support them. eg investigating the possible specialist markets for newer technologies such as functionally graded materials, medical implants, nanopowders, and intermetallics.

A powder handling/delivery task force should be set up under a trade association initiative.

Compaction modelling required for technical and economic reasons.

Computer simulation of die filling should be carried out, including magnetic assistance of the filling process.

Consideration should be given to setting up an expert system for PM design.

Specific recommendations for the structural components sector include:
- follow up the 1992 Delphic survey.
- provide a critical review of technical literature to aid decision making on R&D.
- the PM should organise the collection of materials data for applications engineering, and survey PM companies for a consensus R & D programme on density improvement; and it should investigate the concept of a Centre for PM technology, probably European in scope, and on a virtual basis.
- obtain comments on proposed R&D actions from the UK PM Network administered by Nottingham University, and discuss with the Network possible R&D strategies for substitution of nickel in PM materials.

A specific recommendation for the magnet sector is that a trade association should initiate discussions on R&D into new magnetic materials.

Specific recommendations for the hardmetals sector are – to consider the case for setting up UK round blank facility, and to initiate an R&D programme into a universal sintering barrier.

A number of suggestions were made with regard to the role of the relevant university departments, which can be summarised as:
- assessment and evaluation of potential for industry sectors to benefit from R&D.
- "watchtower" concept for intelligence on development possibilities.
- "technology councillors" for SMEs.
- better organised teaching company projects with better definition of objectives, deliverables, and FRD potential.
- participation in small "hit squads" to provide nap and concentrated input to stated problems or threats.
- the PM industry should consider an initiative along the lines of the Integrated Graduate Development Scheme (IGDS).

While the project highlighted a large number of issues (the above being only a selection), several