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The importance of information to the Circular Economy

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Introduction

Metals are fundamental to modern life. They are used in all areas of society from transport, energy production, construction to packaging and the metals supply chain contributes £10.7bn to the UK economy. The high volumes of metals used in the UK and the nature of their manufacturing processes mean that they are responsible for large quantities of carbon dioxide emissions. The Stern review of 2006 quantified its severe consequences to human society and in response, the UK passed the Climate Change Act (2008), amended in 2019, to target net-zero emissions by 2050. Analyses by the EC and the Energy Transitions Commission, a think-tank, show that the UK can only achieve this ambition by fundamentally reducing its demand for carbon intensive virgin metals by increasing 'material efficiency' and 'circularity'. This is because, unlike sectors such as transportation, metal production is difficult to electrify with renewable energy sources, making their emissions difficult to abate.

Circularity or the circular economy is a framework of three broad principles: eliminate waste, keep materials and resources in use and regenerate natural systems. For metal production, the first two principles increase material efficiency. Specifically, this can be achieved by reducing material usage, reusing, remanufacturing and recycling when it is not possible to reuse and remanufacture.

Apart from reducing, increasing circularity will require the development of techniques to identify the quality of end-of-life products. George Akerlof observed in his ground-breaking paper, 'The Market for Lemons: Quality Uncertainty and the Market Mechanism', that used products are characterised by variable quality and that this quality is difficult to quantify in a marketplace. This creates an 'information asymmetry' in the market where sellers know more than buyers about product quality. This information asymmetry favours the sale of poor-quality products (or lemons), resulting in low prices and market failure. Avoiding this failure will require efficient and cost-effective techniques that extract the critical information from end-of-life products that indicate its quality. For reuse, remanufacturing and recycling, this is a fundamental requirement because it allows the market to make accurate valuations, which in turn is the necessary condition for the growth of circular supply chains.

Current research

The importance of growing the circular economy means that it is central to the UK's Net-Zero Build Back Greener strategy. According to Innovate UK, the UK currently has low levels of circularity. To transition the economy from its current linear 'make-use-dispose' model to greater circularity, the government is investing in material and sector-specific research programmes, all of which require materials information elements to open up opportunities for circularity. Two of the largest include the Interdisciplinary Centre for Circular Metals (CircularMetal, http://www.circularmetal.co.uk) that is part of the National Interdisciplinary Circular Economy Research Programme (a four-year £30 million programme from 2021) and the SUSTAIN Future Steel Research Manufacturing Hub (https://www.sustainsteel.ac.uk, a seven year £35m programme from 2019). Smaller programmes include EPSRC's Circular Economy Network+ in Transportation Systems (CENTS). CircularMetal aims to enable full metal circulation through research to drive reduction, reuse, remanufacture and recycling metals. It is investigating the technical potential for rationalising the number of steel and aluminium grades for ease of recycling, developing the technologies necessary for greater circulation of metals, exploring new circular business models and understand the resulting underpinning economic flows. SUSTAIN aims to develop the scientific systems and engineering solutions that leads to sustainable steel production. An aspect of the programme will be to create digital techniques for sustainable steelmaking and is linked to the Materials Made Smarter Hub. CENTS is a network programme to build a community around developing the circular economy specifically for transport systems.

Research within these programmes are investigating different methods for identifying the information required to determine the quality of end-of-life materials. For example, monitoring the way products are used in service to determine remaining life at end of product life and identifying material chemical data during recycling to allow them to be separated into appropriate waste streams for recycling.

As sensors become cheaper, accelerometers are increasingly fixed on products to monitor usage and the information can be used to estimate the mechanical condition or fatigue life of components at the end-of-life. These sensors add functionality to products (eg. by warning of overloading of structures) but are also able to measure in service loads that can be compared to design loads. Activities within the CircularMetals and CENTS projects are creating digital twins of heavy-duty off-road vehicles that will collect and feed this data into a machine learning model to identify the way and the length of time the product was used. At end-of-life, the aim will be to input the usage pattern into a finite-element model to calculate remaining fatigue life of the vehicle. The fatigue life parameter characterises the mechanical condition of the product and allows decisions to be made about whether to reuse (if it was lightly used), remanufacture (if it was moderately used) or recycle (if it was heavily used) the product.

For recycling, the challenge is to identify the chemical data from a pile of scrap to separate the individual types and grades of metal. Using steel as an example, recycling high-quality steels will reduce demand for making primary steel from iron ore and coking coal. The fundamental challenge is to improve the current poor quality of steel scrap so that it can be made into a similar product-class without degradation of the material through impurities.

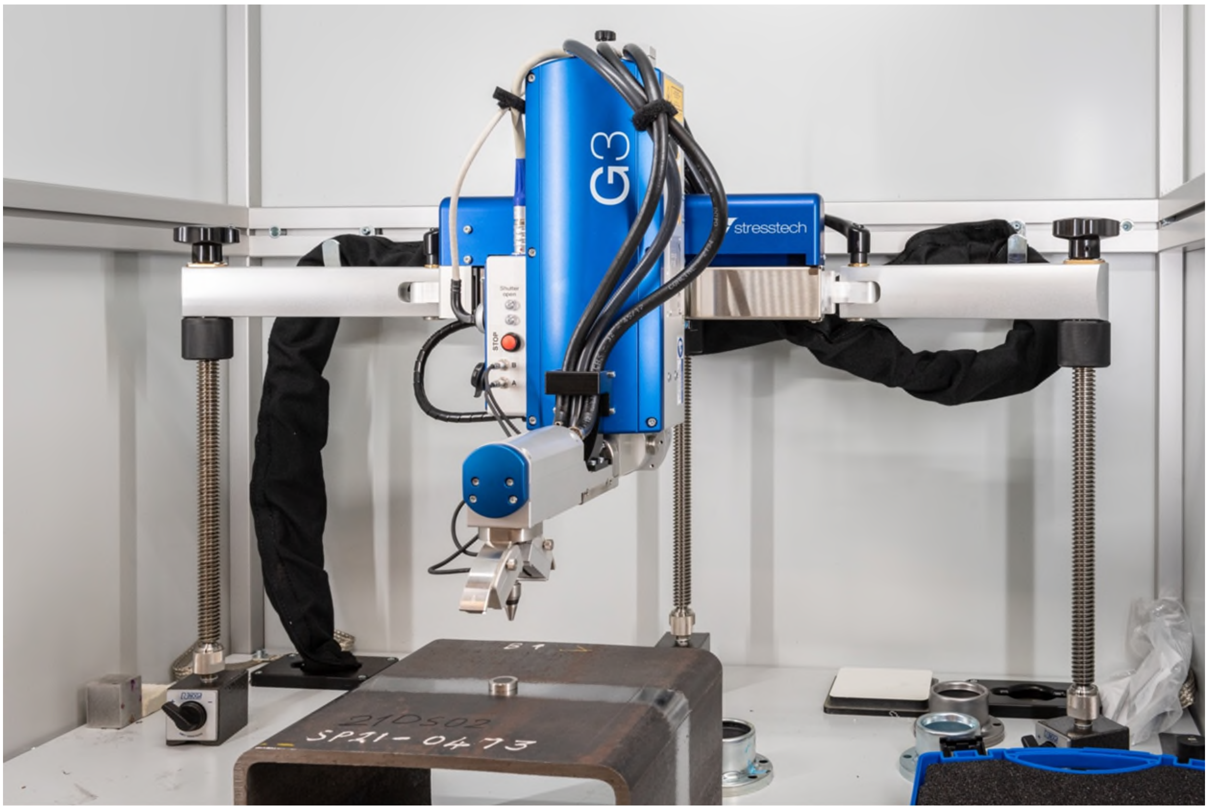
This rarely occurs now. Steel scrap is currently generated from many sources such as domestic and manufacturing waste. Poor or unknown quality scrap is caused by mixing large volumes of steel scrap from these different and varied sources. As a result, the resulting mixture will contain materials such as plastics, glass and metals in unknown compositions and grade. This random mixing introduces various impurity elements, such as copper and tin, which can be detrimental to the subsequent processability and quality of steel products. In an attempt to 'purify' the scrap, it may be visually inspected, hand sampled and spot checked by hand-held X-Ray fluorescence to separate and control the quality of steel scrap. Globally, even the regulated disposal of the end-of-life vehicles involves processes such as shredding that do not consider closed-loop recycling. The UK has a relatively mature metals recycling sector that carries out this processing. It sells the processed recycled material to steelmaking companies who convert it to crude steel through melting. Frequently, the resulting material will have to be 'downcycled', as they will not be suitable for use in products they originated from.

Invariably, the highly manual nature of current sorting of scrap leads to poor quality recycled material. CircularMetals and SUSTAIN projects are focussing on improving the sortation technique by developing cost-effective digital systems where sensors that image and carry out rapid spectroscopy (eg. with Laser Induced Breakdown Spectroscopy) on the scrap are combined with artificial intelligence techniques to accurately identify their chemical compositions and therefore, their grade. Using chemical information to separate scrap into constituent grades will lead to higher value scrap through increased confidence in the marketplace and ultimately to higher quality recycled products.

Future uses of information

To move beyond discrete circular applications, the use and sharing of information has to be formalised (say, through a standardised framework) to manage how it may be used through the life-cycle of a product: product development, product use and product end-of-life. Currently, information within each stage is strictly contained within it. For example, the fatigue calculation of a product will remain within product development and is not shared at the product end-of-life for future processing. Some important aspects of this information sharing framework have been developed. Dr. Norman Swindells (Materials World June 2020) has described ISO 10303-235 Engineering properties and materials information, part of the ISO 10303 Product data representation and exchange series, to standardise the way in which digital materials property information is represented, independent of the proprietary software used to generate the data. This will allow material information (such as material composition and dimensions) to be shared more easily. However, it may need to be accompanied by legislation that regulates sharing and protects intellectual property, particularly for end-of-life processing by third party supply chains.

The benefits of such a framework could be considerable. Knowing the properties of materials in a product will make it cost-effective for products to be dismantled selectively for remanufacture where possible, or fully dismantled for separation into appropriate waste streams for recycling, thus minimising impurities. More broadly, a formal system of sharing information will clarify the principles and regulations for the UK's circular economy, making it easier for consumers to make informed decisions and for industry to grow and sustain new supply chains.



A G3 StressTech X-Ray diffractometer at WMG that can be used to identify residual stresses in a used component. Photo courtesy of Fanfu Wu © 2021.