Innovations in Everyday Engineering Materials

Authors: **DebRoy, T., Bhadeshia, H. K. D. H**.

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1. A Remarkable Innovation in Stainless Steel Making: This story is about a young engineer, who when faced with conflicting data, refused to ignore the discrepancies, followed them up and as a result, created a disruptive technology that has changed the scenario for stainless steels. It shows corporate research at its best, with generic lessons for those yearning for novelty that changes established practice for the better. The experiments that led to the breakthrough, how they were scaled for manufacture, the ubiquitous adoption of the new process, and much more is described.

2. Dazzling Diamonds Grown from Gases: Natural diamonds are difficult to mine. This, combined with marketing strategies, make them expensive and once polished to sparkle, they make the kind of gift that might seal a relationship between humans. However, their utility spans well beyond their dazzle. There is therefore a myriad of engineering applications, such as in high-temperature electronics, cutting tool, and windows that are transparent to X-rays, microwaves and infrared radiations. Many of these applications require diamonds to have large and non-planar surfaces. This limits the use of natural diamonds in some functional applications. Diamonds deposited from a vapor can overcome these difficulties. Industrial diamonds are now difficult to distinguish from those that are mined.

3. Stirring solid metals to sound welds: Friction stir welding does not generate fumes and there is no loss of volatile alloying elements. This remarkable process maintains the solid-state during welding and yet is able to fabricate structurally sound joints. A robust spinning-tool rubs against the abutting parts that require joining, generates heat by friction, thus softening the metals without melting it. The translation of the spinning-tool along the joint-line forges the pieces together under great pressure. The lack of melting means that it is possible to join dissimilar metals or very difficult metals that cannot otherwise be joined. In spite of its relatively recent invention, the process is now ubiquitous in the welding of aluminum alloys in particular, but with many efforts to extend its horizon, for example to the microelectronics field.

4. Picture to parts, one thin metal layer at a time: Additive manufacturing is a manufacturing process that creates three-dimensional objects by progressively depositing thin layers of material guided by a digital drawing. The creation of metallic objects using this technology is one of the fastest growing implementations, although other materials such as concrete, ceramics and polymers are also amenable to this manufacturing process, enabling applications that might not otherwise have been possible. Stainless steels, aluminum, titanium, and nickel alloys in the form of powders or wires are melted by heating with a high-energy source such as a laser beam, electron beam, or an electric arc. Metal printing is now used in aerospace, consumer products, health care, energy, automotive, marine, and other industries because in cases where it has advantages over conventional methods. Here we examine the key processes and principles for printing metallic parts, their unique features, and review how their microstructure and properties develop.

5. Welding: the digital experience: Our understanding of welding has evolved mostly through experiments which have contributed so much to the success of the process. However, in some cases experiments alone are not able to provide the insights needed to drive the most difficult of advanced materials engineering. It is impossible, for example, to determine the entire flow field within a weld pool, knowledge that can be critical in determining the ability of the pool to penetrate the joint. Well-tested mechanistic models of welding can do this quite effectively and inform on the best way forward. There are even occasions where the models can lead to entirely unexpected outcomes. A few of these concepts are illustrated here as an introduction to the power of the digital intervention in welding.

6. Inventions that enabled the silicon age: Silicon based electronic devices are all-pervasive, though this might have been unimaginable just a few decades ago. Their manufacture requires silicon with extreme purity, with less than one foreign atom per ten million of silicon. There are innovative processes which have enabled the mass production of such silicon. The base for discussion is the silicon that has been made since the nineteenth century for metallurgical applications, where the demands on purity are much less onerous. This is followed by the story of pure silicon crystals with minimal defects in their periodic structure, essential in the making of reliable semiconducting devices that are so remarkably affordable, so much so that there are now 56 billion transistors in existence per living person.

7. Transition to sustainable steelmaking: It would be hard to imagine a modern society without steel. Nevertheless, its production is a major contributor to carbon dioxide emissions that contribute to climate change. With the growing awareness of the damage that is caused by the accumulation of carbon dioxide in the atmosphere, the search for sustainable production technologies has intensified in recent decades. A few attractive concepts have emerged but are not yet ready for deployment. The development of innovative greenish technologies and their commercial viability will depend on the implementation of appropriate policies for environmental protection. Here we assess the reasons why steel production pollutes so much, the current status of sustainable technologies, and the policies that might make for a better future.

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8. First bulk nanostructured metal: Sometimes, a combination of deep knowledge, serendipity and perseverance can lead to developments that set aside decades of attempts. The story of the world's first bulk nanostructured metal is an example of this. The phase change that led to the material was, back in the 1970s, so controversial that textbooks of the time would not dare to venture opinions. The subject has calmed over a period of about half a century, so much so that the theory can be used to create materials that fire the imagination. The story is illustrated here.

9. High-entropy alloys: Most metallic alloys contain small concentrations of solutes because they are sufficient to achieve amazing properties on a grand scale of production and utilization. In the early 1980s, a different concept was introduced that involved mixing large concentrations of solutes in roughly equal amounts so that there is no predominant solvent. When this happens, the degree of disorder increases and this can contribute to thermodynamic stability so that the alloy remains as a single phase in spite of the usual tendency of decomposition as solubility limits are exceeded. Whether or not this leads to properties that are unique and affordable remains to be seen, but it is clear that there are possibilities that deserve investigation.

10. Metals that do not forget: A crystal is defined by the pattern in which the atoms within are arranged. This pattern can in the right circumstances, undergo a transformation into a new arrangement that has a different symmetry. One of the ways in which such a change can be achieved is by a homogeneous deformation which leaves all near-neighbor relationships intact. This represents a particular class of transformations that are known as martensitic transformations. There is no diffusion required and there is no composition change. As a result, the martensite retains a memory of the arrangement of atoms in the parent structure so a reversal of the transformation also reverses the deformation. We shall see in this chapter how this memory effect can be exploited to create devices that are life-changing and others that improve the ability to engineer improved mechanical devices.

11. Low-density steels: Iron ordinarily has a density that in the context of aluminum, silicon, magnesium, and lithium, is large. It nevertheless has properties that are so superior that the quantity of iron used exceeds that of all other metals combined by a very large amount. However, there are specific engineering applications where it would be a tremendous advantage to have all the properties of iron but at a smaller density. The methods available for achieving this goal are described here. There has been substantial progress and some low-density iron alloys are now commercially available.

12. Secrets of ageless iron landmarks: Metals and alloys are exposed to environment have a tendency to react with oxygen, moisture and other gases. They therefore need to be protected to avoid degradation. However, there are several iconic structures that are over a thousand years old, have not been protected and yet, are quite intact. Recent research has revealed some of the secrets behind their unexpected endurance.

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