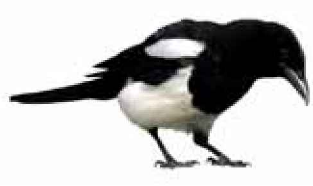
14 Diverting manufacturing scrap

to other uses before recycling by melting

With high yield losses currently in production, and with additional scrappage from defects and over-ordering, could we avoid sending scrap for recycling by melting and instead use it elsewhere?

The European Magpie is a remarkable bird: thought to be the most intelligent of animals or birds, its neostriatum—a region of the brain associated with the executive functions required to cope with novel or unusual situations—has the same relative size as that of humans. The Magpie is of course black and white, so with the pungent poetry for which contemporary football is famous, the English teams of both Newcastle United and Notts County, who play in black and white, are nicknamed 'The Magpies'. And of most interest to us, the Magpie has a reputation as a thief and hoarder, particularly of shiny objects. In Rossini's opera La Gazza Ladra (The Thieving Magpie), the lovely Ninetta escapes by seconds a sentence of death imposed on her for stealing silver cutlery, only because the true culprit, the Magpie, is caught re-offending.



The European Magpie

A quick survey of our nation's garages and sheds would reveal that in fact we're all Magpies. We're attracted to shiny, or not so shiny, metal objects that have passed through our hands, and store them because 'they might come in useful'. We have an instinctive sense that old metal objects have value.

Could we be more intelligent in hoarding our shiny production scrap? If we chose to keep our scrap and not melt it, would we find a different use for it? We'll separate our answer to this question across two chapters: in the next chapter we'll look for opportunities to re-use components at the end of their first useful life, but in this one, we'll examine whether we can divert scrap arising along the production chain. We've seen in the Sankey diagrams of metal flow, and in the last chapter on yield losses, just how large this supply of scrap is—is it always best to melt it in a recycling loop, or could we divert some of the scrap back into use, with less energy?

We'll start by examining scrap as it is created: what have we got and in what volume? Then we'll look at opportunities to divert scrap of different types into use, and finally move on to looking at the barriers to increasing scrap diversion in future.

Where does metal scrap arise and in what form?

The magpie in British folklore is a bringer of bad luck, a harbinger of bad weather, and foreteller of death. So, is collecting metal scrap good news, or a prophecy of commercial doom? In contrast to the post-consumer scrap favoured by magpies, manufacturers know precisely the composition and history of steel and aluminium scrap generated in production, so can avoid mixing up different alloys. Such scrap is also typically in good condition, without surface corrosion (although it may be covered in a lubricant), and has not been assembled into a product, so requires no disassembly. So we are likely to have better luck looking for opportunities to divert scrap from production than after use.

A typical 'skeleton', left over after blanking

According to our Sankey diagram of steel flows, 30% of steel scrap comes from the forming processes of the steel industry, from the beginning and ends of castings, and from trimming the heads, tails and edges of rolled material. The remainder arises in fabrication and manufacturing. Our work in the previous chapter suggests that yield losses for long products such as the I-beam are relatively small, so the largest fraction of steel scrap arises from cutting out non-tessellating shapes from blanking rolled strip and trimming after forming. The sheet and plate material left after blanking is called the 'blanking skeleton' and this is probably the most useful form of steel scrap. Half of all steel fabrication scrap comes from rolled strip and plate, and from the last chapter let's assume half of this is due to trimming after forming, so around 60 Mt of steel per year scrapped as blanking skeletons. What else could we usefully cut out from the blanking skeleton? One answer is shown in Figure 14.1: if we wanted to cut out smaller versions of the same shape (circles in this case with diameter around 15% of the original), this would reduce the blanking skeleton scrap by about half. Extrapolating this simple estimate, around 30 Mt of steel sheet and plate blanking skeletons might be diverted into use, if we could find customers for the smaller shapes.

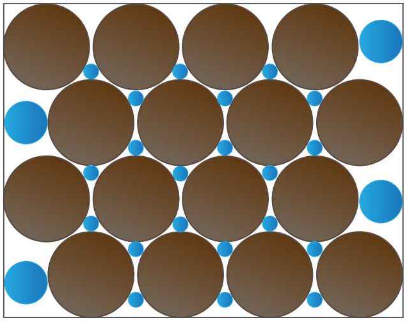


Figure 14.1—**A possible use (blue) of material left over after cutting circular blanks**

The Sankey diagram of aluminium flow tells quite a different story, with two thirds of aluminium scrap arising within the aluminium industry, particularly due to cutting heads and tails off ingots, ingot scalping, and machining parts from cast products. Just one third of aluminium scrap arises in downstream fabrication and manufacturing. The heads and tails of ingots are large blocks, but scalping and machining scrap is in the form of swarf, or aluminium chips. Our yield loss case studies in the previous chapter showed that around 10% of metal cast for the aluminium car door panel becomes swarf. However over 60% of the metal cast for the wing skin panel is turned into swarf, and for directly cast products, all scrap will be in the form of swarf. So, looking at the global Sankey diagram, we

Aluminium machining swarf

Over-ordered material, in excellent condition, being transported for scrap

estimate that of the 76 Mt of liquid aluminium produced each year, between 10 and 20 Mt of it will be made into swarf.

One final important source of scrap arises due to over-ordering. This is common in construction, where projects will be delayed at high cost if there is a delay finding material. Over-ordered material is generally collected and recycled efficiently, but of course it could also be resold. A high profile example of this form of scrap diversion occurred during construction for the 2012 London Olympics: the roof trusses of the main stadium are made from over-ordered oil and gas pipeline. More details about this in our box story.

We don't know the volumes of over-ordered steel and aluminium components that are sent for recycling. However, through visits to metal scrap yards in the UK, we found that scrap merchants increasingly keep such good quality material separately while searching for customers who will re-use it directly.

Our survey of scrap creating, has identified two interesting high-volume streams of scrap: steel skeletons and aluminium swarf. Can we divert these streams back into use without melting?

Truss structure in the Olympic Stadium, Olympic Park London

The truss structure for the Olympic Stadium uses 2,500 tonnes of "non-prime" steel tube, over-ordered from an oil and gas pipeline project. The original stadium design had specified large diameter steel tubes, but the fabricator was concerned that the delays in purchasing new steel, and the difficulty of manufacturing these specialised sections, might delay construction. So the Olympic Delivery Authority (ODA) and Team Stadium chose to use this over-ordered stock to remove the risk of delays and to reduce the embodied emissions in the stadium.

The second-hand tubes were supplied without certification, so coupon tests, using small lengths of steel cut from each tube, were conducted to confirm their mechanical properties. Each 12-metre tube length was tested and then welded into 15-metre span lengths while the structural design of the truss was modified. The additional design time was modest, and despite having to over-specify some structural members, no additional weight was added to the structure. As a result of this action, 20% of the steel used in the stadium is diverted scrap. Although their motivation was to reduce project risk, and despite the additional design and testing effort, Team Stadium were delighted to find that reusing steel gave a small reduction in total project costs.

What opportunities are there to divert scrap into use?

According to Shakespeare's Macbeth, in his growing madness, "Augurs and understood relations have by magpies and choughs and rooks brought forth the secret'st man of blood." So if the magpie can lead to revelations about murder, can we reveal opportunities to extract value from our shiny scrap?

Scrapped structural steel sections

Blanking skeletons are a supply of perfect quality material from which smaller blanks could be cut. There is no technical difficulty in this apart from the problems with blanking-press design discussed in the previous chapter. The best solution for diverting scrap from blanking skeletons would be to use blanking presses to exploit every last square millimetre of each sheet. That however requires process development, while at present, on many blanking lines, the skeleton is chopped into small pieces for easier collection. An alternative, if the skeleton can be removed from the press intact, is to ship it to a separate business who will cut out the large pieces. Step forward Abbey Steel in Kettering, described in our box story, who for thirty years have purchased blanking skeletons and other trim (such as the window cut-outs in door panels) from car manufacturers in the UK. They then cut regular shapes from these skeletons, and supply them as blanks to firms making small parts. Abbey Steel exemplify the profitable diversion of blanking scrap, and tell us they could serve more customers if only they could persuade more car manufacturers to hand over their scrap.

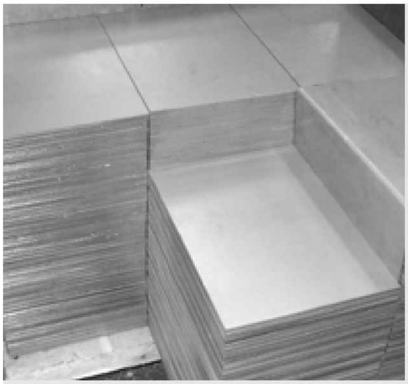
The other major source of scrap that could be diverted is aluminium swarf. This sounds rather unpromising: our childrens' guinea pigs go to sleep at night on a bed of wooden chips, but surely not even a magpie would feather its nest with aluminium swarf? Surely no-one wants swarf except for melting. Yet several years ago we learnt of a series of trials carried out in Wrocław in Poland, by Professor Gronostajski and his son, Professor Gronostajski, examining the solid bonding of aluminium chips. Aluminium is a very reactive metal, and as we learned in chapter 3, under normal conditions 'naked' aluminium will rapidly and within milliseconds react (join) with oxygen atoms in the air to form a thin protective layer of aluminium oxide. However, if we were able to bring together two 'naked' surfaces of aluminium, with no oxygen present, the two surfaces would instead react with each other, and bond. So, pure aluminium will weld to itself at room temperature, and this gives us a chance to re-use aluminium swarf without melting.

This solid bonding is related to techniques developed in Japan over 1,000 years ago to make the Katana (刀), the traditional sword of the Samurai. Iron sand and charcoal would be heated in a traditional Japanese furnace, known as a tatara, to

A 'Katana' or Samurai Sword

produce the crude tamahagane steel for the sword. The master swordsmith would then carefully pick the right pieces of steel for making the sword. The colour of the steel determined his selection, as it is indicative of the carbon content: too little carbon and the blade will not be hard enough to give the required razor-sharp cutting edge; too much carbon and the blade will be too brittle for use. Small pieces of the selected steel were then heated to just below the melting point, and hammered into a welded block. This block would be repeatedly heated, folded and beaten, the interface between each layer welding under the compressive pressure of repeated blows. More than ten such folding operations produced hundreds of layers in the steel, spreading the carbon content and impurities more evenly and creating a fine grain size and an excellent sword. The katana sword was used by the samurai for centuries, and is an iconic symbol of weaponry and metal artistry.

So the Samurai warriors gained strength from swords that were folded and welded while solid but hot. The aerospace industry has explored a similar approach to create very high strength aluminium sheets by accumulative roll bonding[1]. One strip of aluminium is stacked on top of another, then joined by rolling. As the two strips pass under the rolls, the oxide layer cracks and naked aluminium is squeezed through the cracks to meet naked metal from the other sheet and so weld. This process can, in principle, be repeated many times to produce a very fine grain size, and hence strong material. The Professors Gronostajski set off on a different route to both the aerospace industry and the master sword smiths of ancient Japan, using extrusion. Extrusion (squeezing metal through a small die), elongates the original



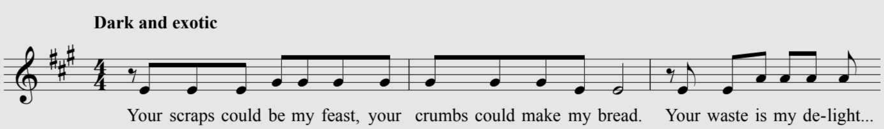
Abbey Steel

When blanks for car body parts are cut from coiled steel strip, 10% or more of the material is wasted because parts do not tessellate perfectly. When they are subsequently pressed on average 50% is lost due to cut-outs (e.g. for car windows) and edge trimming. Abbey Steel, a family run business in Stevenage, has for 30 years bought, trimmed and re-sold around 10,000 tonnes per year of these cut-outs. They are used for noncritical parts by manufacturers of small components including filing cabinets, electrical connectors and shelving. Abbey Steel pays a premium over the scrap price to collect the cut outs, trims them into rectangles according to demand and sells them on at a discount relative to new stock. The business would grow more if press shops could segregate more cut-outs for resale.

material while compressing it and extruding clean aluminium swarf, creates a new, well-bonded solid with remarkably good properties: similar strength, but reduced ductility, compared with the original material. An attraction of this approach is that it saves over 90% of the energy directly associated with melting in conventional recycling. In addition, recycling chips by melting gives a yield of around 50% but by solid bonding has a yield nearer to 90%.

Solid bonding of swarf is still in development, and with our colleagues at the University of Dortmund, we're attempting to understand it better (more details in the box story). But with around 10–20 Mt of aluminium swarf to play with, this looks like it might be an attractive option for the future.

In this section we've seen that two major streams of scrap might be diverted from melting, as there are viable low energy routes to making use of the scrap without melting.



What are the barriers to scrap diversion and can they be overcome?

The magpie is a common national symbol in Korea, where it's seen as a bird of great good fortune, of sturdy spirit and a provider of prosperity and development. Both of our routes for diverting scrap are technically possible, but neither has yet led to widespread prosperity and development. Is it just the lack of a sturdy spirit that's holding back the adoption of scrap diversion?

Most downstream manufacturing and fabrication businesses do not see their scrap as part of their core business. Typically, scrap handling systems are designed to prevent disruption, and to dispatch scrap as rapidly as possible. Production lines have generally been designed without considering value in scrap so, as we saw, larger blanking skeletons are chopped into small pieces for ease of handling, and swarf in machining shops while separated by metal family is rarely separated by alloy. One aeroplane manufacturer told us that they sell their swarf with all alloys mixed and for a price of around 1% of what they paid for it, yet swarf is 90% of their output. If the solid bonding process is developed further, this manufacturer

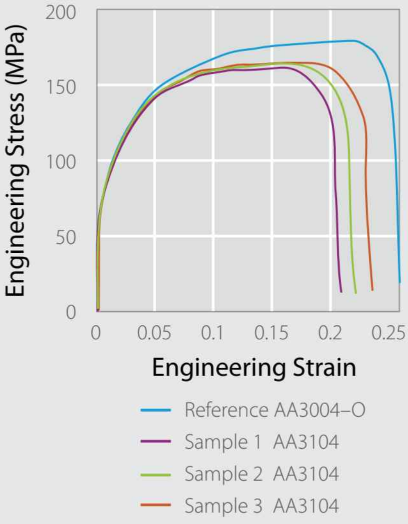
Early solid bonding trials to create a box section

might in future have an extrusion press adjacent to its machining line, to convert swarf into bars of known single alloy composition. These could either be used directly, or recycled by melting but with much higher yields and value than at present.

Upstream, we have seen careful handling of different alloys, but only in 'melt shops' where aluminium casting occurs. Here, the heads, tails and scalping swarf from ingots of different alloys are carefully segregated, so they can be fed back into future melts without disrupting composition.

So lack of awareness, the design of current waste handling systems, and alloy mixing in waste streams all inhibit the opportunity to divert scrap from recycling by melting. In addition it may be necessary to clean scrap prior to diversion, to remove rust, coatings or lubricants, and because scrap is only traded at present prior to recycling by melting, finding customers for blanking skeletons may take time and require stock-holding.

Scrap diversion, and indeed all recycling, would be simplified if we could reduce the variety of alloy compositions in use. Competition between metal suppliers tends to have the opposite effect, and each year the number of alloys on the market



Solid bonding trials

In ongoing trials, we're working with our partners at the University of Dortmund to develop and evaluate solid bonding, aiming to promote the technique as a commercial alternative to recycling by melting of aluminium swarf.

We have tested the process using AA3104 (drinks can body material), AA6060 (automotive bright trim), and AA6061 and AA7070 (aerospace machining swarf), and all tests have produced specimens of high quality. The graph presents tensile test data for samples made from extruded AA3104 chips. The solid bonded material shows similar performance to the reference material, with reductions of around 10% in ultimate tensile strength and 15% in ductility. We anticipate that with further development we will be able to reduce these differences and in parallel we're assessing process reliability.

In many applications (such as aluminium window frames or decorative trim) the full strength and ductility of the original aluminium is not required, so potentially solid bonded material could be used instead. We're currently working with a leading car maker to produce automotive bright trim for a new car from aerospace swarf.

increases. Each new alloy is optimised for a particular application, and as we saw in chapter 12, careful material selection can facilitate lighter designs. However, this variety inhibits re-use and recycling, so designers now, and policy makers in future, may choose a reduced range of alloys.

Outlook

We've estimated that up to 30 Mt of steel blanking skeletons and 10–20 Mt of aluminium swarf could be diverted to other use rather than being recycled by melting. This is technically possible, but inhibited by various features of current practice. If we could achieve this diversion, how would it affect global emissions figures for the two sectors?

Diverting scrap would create a new loop on our metal flow Sankey diagrams—from scrap back into fabrication. This would reduce the flow of metal entering secondary production, while simultaneously reducing demand for metal made by this route. The two options for scrap diversion in this chapter require little further processing energy, so compared with existing recycling processes, they might save 11 GJ/tonne for steel, 13 GJ/tonne for aluminium, or equivalently about 0.7 tonnes CO_2/tonne for both metals.

Diverting scrap is potentially a significant emissions abatement strategy but as we saw in chapter 13, because it diverts metal from secondary production not primary, it has less effect on total emissions than reducing total demand for metal through design, as discussed in chapter 12.

In Norway, the magpie has a wonderfully diverse role in legend: cunning, a thief, associated with the devil and guardian of the household. For any negative connotations we now have the Samurai's sword to silence the magpie for good, but instead let's leave him in a positive role: a playful, loud Norwegian magpie is a bringer of good weather, so we'll keep playing with solid bonding and shouting loudly about the opportunity to improve the weather by diverting swarf and blanking skeletons into other uses.

Notes

1. In the 1990s severe plastic deformation of metals was investigated as a method of producing ultra-fine grains less than 1 μm in diameter, producing associated high strength. However, most of the processes investigated were only suitable for small samples due to the high pressures involved. Saito et al. (1999), however, developed a repeatable rolling deformation for the intense straining of bulk materials. This process is known as accumulative roll bonding.