Recycling, reuse and the sustainability of steel

Recycling and reuse significantly improve the sustainability of steel product systems. Life cycle assessment methods are used to quantify the benefits of both recycling and reuse and illustrate that, for typical construction applications, steel has a whole life energy burden of approximately 11MJ/kg, which is about 50% of the burdens without recycling. Understanding the factors that influence the sustainability of steel requires an analysis of the full product life cycle.

INTRODUCTORY THEMES

Fig.1 Crude steel production and scrap consumption

Recycling and reuse significantly improve the sustainability of steel product systems. Life cycle assessment methods are used to quantify the benefits of both recycling and reuse and illustrate that, for typical construction applications, steel has a whole life energy burden of approximately 11MJ/kg, which is about 50% of the burdens without recycling. Understanding the factors that influence the sustainability of steel requires an analysis of the full product life cycle.
The lifespan of various steel products, the amount of steel that went into those products (in the year that corresponds to their average lifespan) and the current rate of collection/recovery (see Table 1). In terms of tonnage, the steel industry’s major market is construction (e.g., buildings) and civil engineering (i.e., infrastructure such as bridges, tunnels and railways). Steel, which is utilised in buildings, has an average lifespan of 50–60 years, while that going into the transport infrastructure, such as bridges, tunnels and roads, has a much greater lifespan, some with no foreseeable ‘end of life’. Hence, the amount of steel that becomes available for recycling, from this market sector, is significantly lower than the amount that is currently being supplied. Referring back to Figure 1, it can be seen that world steel production 50 years ago was only 20% of current production, so it is reasonable to assume that the amount available for recycling from the construction sector will be only about 20% of current supply. The construction sector, however, does have a good collection rate (>85%), which means that most of the available material from this sector is ultimately recycled. Figure 2 shows an example of how a steel-intensive building, after 50 years of useful life, has been demolished for recycling.

Steel products supplied to the automotive sector have an average lifespan of 12 years; hence, the amount of steel arising for recycling, from this sector, will be related to the material supplied into the automotive sector 12 years beforehand. Steel supply into the UK’s automotive market has been fairly stable for the past 20 years, which means that the amount available for collection will be similar to the amount currently being supplied. The collection rate for the automotive sector is also very good (approximately 95%), which means that most of the steel is recovered for recycling. Packaging materials, in contrast, have an average lifespan of approximately one year, so the amount of steel that could be collected, in any given year, is virtually the same as the previous year’s supply into that sector. With packaging materials, however, the collection rate is typically 60%, as a significant proportion is currently lost to landfill, through the domestic waste stream. Figure 3 shows some examples of steel recovery for recycling.

The cumulative effect, from all market sectors, means that the amount of steel available for recycling will always be significantly lower than the current world demand for new steel products. Hence, for the foreseeable future, a large proportion of new steel will have to be produced from virgin iron ore in order to meet the ever-increasing world demand for steel and its products. High scrap recovery rates (>85% in construction) compared to an average recycled content of approximately 40%, represents a paradox for steel. This paradox can be explained by world steel demand and the useful life of steel products, which both influence recycled content.
STEEL REUSE

Reuse describes any process where end-of-life steel is not remelted but enters a new product use phase. Reuse is another aspect of sustainability that is important for materials generally, but steel in particular as it is present in many products that are reused. Reuse, like remelting, saves valuable raw materials and energy; the durability of steel makes it suitable for products designed for reuse. Examples include the redistribution of used steel drums, use of old cladding panels for new buildings, and reuse of automotive parts. Generally, reuse is more sustainable than recycling since the energy of remanufacture or refurbishment is relatively small compared to the energy of remelting.

LIFE CYCLE ASSESSMENT

To quantify the benefits of reuse and recycling in terms of sustainability, one approach is to look at the environmental credentials of steel, in the form of a Life Cycle Assessment (LCA). Since the mid-1990s the International Iron and Steel Institute (IISI) has been involved in generating LCA information for steel industry products. When performing a LCA it is important to define a reference point (or functional unit), to which environmental burdens can be apportioned. Environmental burdens can be recorded as a series of flows (eg, emissions to air and water) known as a Life Cycle Inventory (LCI) and these flows are recorded from earth’s resource up to a defined boundary (eg, a factory gate). For the purposes of this paper, the functional unit is defined as the provision of 1kg of steel for use by society.

To evaluate the LCI, under this definition, it is necessary to consider all the stages that the material might go through from initial manufacture, use, reuse and recycling to final disposal. By taking a long-term view over many years a material will exhibit an environmental burden to society based on the number of product cycles. This approach considers the impact of multiple life cycles on the environmental credentials of a material.

MULTIPLE LIFE CYCLE METHOD

A methodology for calculating the environmental cost of a material that undergoes recycling and reuse during its life has been published previously [2]. This methodology focuses on the impacts of the material production and not on the ‘use’ phase of the product application, and provides a useful basis for quantifying the benefits of recycling and reuse. For example, a primary process yields 1kg of a product and this material is reused or recycled after use to produce \( r \) kg of product (where \( r \) equates to the overall recycling/reuse efficiency over one life cycle). Throughout \( n \) life cycle stages (where \( n = 1 \) for the primary stage) the LCI (\( X \)) can be expressed as:

\[
X = (X_{pr} - X_{re}) \left( \frac{1 - r}{1 - r^n} \right) + X_{re}
\]

Where \( X_{pr} \) is the LCI to manufacture 1 kg of steel via the primary route and \( X_{re} \) is the LCI to manufacture 1 kg of steel via the recycling/reuse route. In a closed or continuous loop system materials will be reused/recycled indefinitely, with losses limited to the efficiency of material recovery and yield of the process. Infinite loop recycling and reuse is the ultimate scenario for minimising the environmental

<table>
<thead>
<tr>
<th>Sector</th>
<th>Life, yr</th>
<th>Recovery rate, %</th>
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<td>&gt;85</td>
</tr>
<tr>
<td>Automotive</td>
<td>12</td>
<td>95</td>
</tr>
<tr>
<td>Packaging</td>
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<td>61</td>
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</tbody>
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Table 1 Typical product lives and recovery rates [1]
burden from primary material. Mathematically, equation (1) simplifies when considering continuous recycling \((n = \infty)\) to:

\[
\text{LCI for the whole system } X = X_{pr} - r(X_{pr} + X_{re})
\]

The multiple life cycle approach is a useful forecasting tool for evaluating the benefits of reuse and recycling because it allows environmental burdens to be calculated over a series of life cycle stages \((n)\). This enables designers to evaluate where the largest environmental savings can be made in multi-life product systems.

One example of multi-reuse is the return of steel oil drums to a supplier who then redistributes them after cleaning and refilling. The oil drums can be refilled a number of times before an end-of-life decision is made to recycle the container. When the system is analysed for primary energy as an LCI flow, the energy associated with making the steel drums is assumed to be similar to that of manufacturing cold-rolled coil \((X_{pr} = 28.1\text{MJ/kg})\) [3]. It can also be assumed that the primary energy used for returning the empty drums, cleaning and repainting is relatively small \((X_{re} = 1\text{MJ/kg})\). During the process of container handling and transport, some of the drums (typically 10%) become damaged and have to be sent for recycling, therefore \(r = 0.9\).

From the multiple reuse/recycling methodology, as described by equation (1) it is possible to calculate the environmental burden as a function of the number of times the material is reused (see Figure 4).

By reusing the steel drums, the environmental cost of making new steel drums is saved. If the reuse of the oil drums continues indefinitely, with damaged containers being replaced with new drums made from new steel, then the primary energy for the whole life cycle of the steel can be calculated from equation (2) as \(3.71\text{MJ/kg}\) \((28.1 + 0.9 \times (1 - 28.1))\). In this case, reuse avoids 87% of the burden of manufacturing new drums.

One example of where the multiple life cycle methodology can be applied to recycling is in the remelting of steel sections from a building. It is assumed that for the first life, the sections are made from virgin steel (where \(X_{pr} = 22\text{MJ/kg}\)). Subsequently, it is assumed that the EAF route is used where the energy used for processing and recycling, \(X_{re} = 10\text{MJ/kg}\) [4]. The overall recycling efficiency \((r)\) includes the yield to recycle the steel in the EAF and the efficiency of recovering the steel at end-of-life \((r = 0.89)\). A plot of primary energy as a function of the number of times the material is recycled \((n)\) can be obtained from equation (1) and is shown in Figure 5. When the material is recycled indefinitely the primary energy is calculated as \(X = 11.34\text{MJ}\).

An accurate analysis of multiple recycling requires an unrealistic amount of data on many product lives. Commonly, therefore, LCA practitioners look only at once-through product systems and do not set the boundary beyond one phase of manufacture, use and end-of-life. A more relevant methodology for carrying out LCA studies that require end-of-life recycling is described using the once-through method.

**ONCE-THROUGH LIFE CYCLE METHOD**

With recycling, it is possible to arrive at the same conclusion, as defined in equation (2) by considering the life cycle of a product system. The systems analysis approach follows a similar procedure to that described in the ISO14040 set of standards on LCA. Within these guidelines, methods are given on how to account for materials that can be recycled when performing an LCA. ISO14041 recognises that recycling a material can take two forms: open loop or closed loop. The definition for a closed loop system, for a material, is stated as ‘no changes occur in the inherent properties of the recycled material’. Under circumstances where the product is not the same, but the material is the same, then the material is still closed loop but the product is described as open loop. Within this framework, steel can be classified as a material recycled in a closed loop system. The standard also states that for such materials ‘the use of secondary material displaces the use of virgin materials’ when discussing the benefit of producing secondary materials.

The first stage in the analysis for steel is to calculate an environmental burden for scrap. This is important because it allows a mechanism to credit systems which produce scrap at the end of their life and debit systems that consume scrap. Using the definitions given in Figure 6, it
is possible to arrive at an environmental burden (LCI) for scrap as shown in equation (3). 1 kg of scrap has the potential to produce $Y$ kg of steel and this avoids the environmental burden of the primary route ($X_{pr}$) but still carries the burden of the recycling process ($X_{re}$).

From systems diagrams of the primary and recycling routes, as shown in Figure 6, it is possible to derive an LCI value for the full life cycle of steel.

**Life Cycle LCI for both routes**

$$X = X_{pr} - (X_{re} + X_{scrap}) RY$$  \hspace{1cm} (4)

Equation (4) is identical to that derived for multiple recycling, equation (2), because $r$ is a combination of recovery ratio and through process yield ($RY \times Y = r$). This methodology described has been recognised by the IISI as the basis for allocating credits for steel scrap recycling [3, 4] and is particularly relevant to the steel market where end of life scrap is always in demand.

As an example of the once-through LCA recycling methodology, consider the case where a building is constructed from steel sections sourced from two different suppliers. One supplier makes sections from 100% recycled material and the other supplier from no recycled material. By considering the origins of an average 1 kg of steel within the building and its subsequent end-of-life, it is possible to calculate a life cycle primary energy for the steel in the building. The relevant data and calculation for the system is shown schematically in Figure 7. Since the steel is recycled at the end of its life it turns out that the recycled content of the steel does not influence the environmental burden (the total primary energy is always $X = 11.34MJ$). The value of $X$ is not defined by the recycled content but by the recovery ratio, through process yield and the burdens of the primary and secondary routes. The life cycle equations also show that the EAF and BF routes are connected to such an extent that their environmental burdens can be considered identical.

**CONCLUSIONS**

Steel is the world's most recyclable material with some 400Mt of steel recycled in 2003. As world steel consumption grows to meet the needs of a developing world, the amount of scrap available from historic infrastructure is not sufficient to meet the demand for new steel; sometimes this is a consequence of steel's durability resulting in long product lives. The percentage of scrap used in new steel (about 40%), is not an indication of its end-of-life recycling rate (for example this is greater than 85% in construction). In this context, the sustainability of steel is not dependent on the recycled content of steel products manufactured today but is entirely dependent on those products being reused and recycled in the future. This should be the focus of any sustainability strategy involving steel.

**REFERENCES**

1] Recycling rate figures from the following sources: Steel Construction Institute (Construction), ACORD 2000 report (Automotive), The Association of European Producers of Steel for Packaging (Packaging).


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