

Using Recyclable Steel Material in Tall Buildings

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Abstract—Recycling steel building components is key to the sustainability of a structure's end-of-life, as it is the most economical solution. In this paper the effects of usage of recycled steel material in tall buildings aspects are investigated.

Keywords—Building, recycled material, steel, structure.

I. INTRODUCTION

CONSTRUCTION sector is one of the main consumers of material and resources. Minimizing energy and resource consumption and increasing material re-use are of vital importance in terms of sustainability. Raw materials are needed where recycled materials fail to meet sectorial requirements in the sense of quality or quantity. Basic raw materials needed in production of steel are metal ores, limestone, petrol, coal, natural gas and other specific minerals. Steel is unique as it uses high level of recycled components and needs fewer raw materials in comparison with other construction systems. Approximately 2.5-3.0kg of raw material is needed for production of 1kg steel. Wastes may be used as in production of side products or energy. Cage of a lightweight steel structure is obtained from 7-8 car scrap page. However, 50 trees are needed to construct the same structure with wood [1]-[3].

II. RECYCLING STEEL MATERIAL

Today, environmental issues are important criteria for material selection. In evaluating the environmental properties of materials, recycling is a key element. Stainless steel objects hardly ever become waste at the end of their useful life. They are systematically separated and recovered to go back into the recycling process. As well as iron, stainless steel contains other valuable raw materials, such as chromium, nickel and molybdenum, which makes recycling stainless steel economically viable. Stainless steel is not just theoretically recyclable. It is in fact actively recycled on a large scale around the world. Stainless steel recycling is a self-sustaining process. Reprocessing stainless steel is economically viable and technically proven. Like any metallic material, stainless steel is produced in a melting process. Production and recycling are not separate steps in the life cycle of the material. They are one and the same process. Most of the components for stainless steel production are recycled stainless steel and other steel alloys. In 2002, around 20 million tones of stainless steel were produced out of approximately 12 million tons of recycled stainless steel and

other recycled ferrous materials. Any stainless steel object has an average recycled content of about 60%. The stainless steel that our industry recycles today may have been put into the market 20 or 30 years ago. The long term average growth rate of stainless steel has been about 5% per year. Even if 100% of the produced stainless steel was recycled, the available material could account for only:

- * 35% of today's production, if the average useful life is 30 years.
- * 20% of today's production if the average useful life is 30years.

With an average content of 25% of old scrap; stainless steel is close to the theoretical maximum content of material from end-of-life products [4].

Steel material meets both human and environment needs. Ecological improvement during construction period includes creative systems optimizing structural services. Performance of the structure is identified by means of lifetime cost. The material with long-term durability makes the structure economic. A way of reducing the rate of depletion of metal reserves is recycling the "metals-in-use". It is widely recognized that recycling metals results in significant savings in energy consumption when compared to primary metal production. While the terms recycling rate and recovery rate are sometimes used interchangeably in the literature, they usually refer to two different measures. The recovery rate is the amount of scrap metal recovered at the end of the useful life of metal, while recycling rate is the amount of scrap metal that contributes to the total consumption of that metal. Currently recycling rates for steel is shown Table I for Australia, United States and the World [5].

A. Production

Steel is made from iron ore. The manufacture of steel products gives rise to waste material such as the pieces at the beginning and the end of a steel coil, the edge pieces cut away from steel sheets and steel products that are rejected for quality reasons. According to a study by the World Steel Association, steel is the world's most recycled material. Steel can be fully recycled indefinitely without weakening its properties. The bulk of the waste material is returned to the company's own steel mill as a raw material. In upgrading, 1-15 per cent of the amount of steel can end up as waste. Development work is being done continually to improve the yield. Recycling significantly reduces carbon dioxide emissions in the steel production process because the use of scrap steel replaces raw materials in iron-making (Figs. 1, 2) [6], [7].

Metal quality and product recovery issues will affect the number of recycles possible in practice. Recycling rates are very dependent on metal prices. Recycling decreases when the

metal prices go down. Recycling rate targets must take into account market growth and metal durability. The maximum amount of a material that can be recovered at any time is a function of the quality put into service one average product life time earlier. The desire for sustainable development and green building practices continue to rise as everyone finds out more about the environmental advantages. Sustainable development is the social, economic, and environmental commitment to growth and development that meet the needs of the present without compromising the ability of future generations to meet their needs. Hot-dip galvanizing can contribute positively to sustainable development initiatives because of its longevity in corrosion protection, 100% recyclability, and minimal environmental impact. The recycling yield of any material is determined by several factors [6].

1. The effectiveness of the recovery process from previous uses.
2. The effectiveness of the collection and sorting system. The steel scrap industry is well established locally, nationally and internally and sorting steel scrap from other materials is uniquely facilitated by its magnetic properties.
3. The technical difficulties of reprocessing. A product can be recovered and collected easily, but its recycling yield will be low if reprocessing is wasteful.

Steel fabrication, which involves the cutting, drilling and fitting of the raw steel members to meet the project specifications, is usually accomplished by a steel fabricator. These fabricators are usually sub-contracted directly by the general contractor to perform this essential activity. Fabricators are responsible to interpret the construction documents, receive the steel, determine the required fabrication, create connections, and bundle the steel for shipment to the job-site. Beam sections and connection sections are combined during this phase of the process flow, but have separate fabrication methods prior to being connected. The primary output from the steel fabrication shop is a “combined member” ready for erection at the construction site. Structural beams are fabricated under the following basic steps. The steel is unloaded at the site, normally by truck delivered either directly from the mill or from a local railhead. The fabricator stocks some common member size, but in the optimal case and in most cases prefers to order steel sections directly from the mill to avoid unnecessary waste. The ordering and shipment process usually takes 4-6 weeks. Once received the members are tagged by job number and begin the in-line process. First, the beams are cut to the required length by heavy duty band saws. The ends of structural members are then drilled to provide for bolted connections. This is primarily done with a drill, but in some cases a punch is used. The members are then passed to a plasma cutter if copes or irregular angles need to be cut. Each section is then handed over to a steel fitter, whose job is to layout, grind and fit the section in accordance with the shop drawings. At this point the fitter will either bolt the connections or temporarily tack the connection, if a welded connection is required. The production of steel beam is energy intensive portion of the overall steel

process flow. It account for 61% of the total energy requirements when compared against the other five product systems associated with the steel process flow, construction (12%), steel fabrication (6%), steel connection production (2%), concrete production (16%), and fireproofing (3%) (Table I). The primary contributors to CO₂ emissions for steel frame buildings are steel beam production at 52% and concrete production at 32%. These two main product systems account for nearly 85% of total CO₂ emissions. This is an apparent result since the steel beams and concrete floor slabs account for a vast majority of the material used in steel-frame construction. Even after extracting the transportation requirement from each product systems, steel beam and concrete production are still the major contributors to CO₂ emissions [14], [15].

B. Recycling Steel Material

All metals are eagerly sought by recycling centers, but steel is especially coveted. Steel can be recycled over and over again. That's because steel retains its strength characteristics throughout endless recycling. Paper, plastic, and wood become more fragile with each recycling. As a matter of fact, steel is the most recycled material on the planet! Eighty million tons of steel are recycled every year just in North America. (The Steel Recycling Institute has a cool counter on its web site that computes the amount of material steel, paper, aluminum, and plastic, being recycled second by second). Steel cans, for example, are recycled at an average rate of 19 billion per year— about 600 cans every second, according to the Green Team. It's estimated that the average American family disposes of 61 pounds of steel and other metal food and beverage containers every month. The America Recycles Day web site states that producing cans from recycled material saves 67% of the energy needed to produce them from raw materials. The Environmental Protection Agency (EPA) says steel contains an average of 77% recycled material. The World Coal Association reports show total steel product production increased 69% in recent years. One reason for the high recycling rate of steel is the ease with which it can be removed from the solid waste stream with giant electromagnets. All other recycled materials have to be sorted by hand, a slow and expensive process. While wood, plastic, and paper lose strength when recycled, steel can be recycled indefinitely without any loss of its inherent properties or strength [9].

Starting from identical assessment approaches for crude steel and identical dimensions after rolling, various steel grades mainly differ in their constituents and heat treatment processes. Tempered steels particularly alloying constituents such as molybdenum, chromium and silicon as well as heat treatment essentially influence life cycle assessment. The gain strength due to the application of micro-alloying elements in combination with thermo mechanical rolling offers great advantages. The application of higher strength steels is advantageous when an increase in strength enables a reduction of steel consumption. This will not only improve life cycle assessment but also the economic efficiency of construction (Table II) [10].

TABLE I
CURRENT RECYCLING RATES OF STEEL [5]

Metal	Recycling rate (%)		
Steel	Australia 36	United states 64	World 47

TABLE II
RECYCLED CONTENT OF DOMESTIC STEEL [1]

Manufacturing Process	Domestic Industry Data	Basic Oxygen Furnace	Electric Arc Furnace
2006 Annual Domestic Production (tons)	105.928.500	46.802.100	59.125.400
Percent Domestic Production Process (%)	100.000%	44.18%	55.82%
Recycled Steel Used in Production	43.08%	12.613.400	33.005.200
Recycled Content (tons)	Post-Consumer	10.534.588	27.526.337
Recycled Content (%)	Post-Industrial	2.096.812	5.478.863
Safer construction	Post-Consumer	22.51%	46.56%
	Post-Industrial	6.19%	26.93%

Carbon footprint describes the lifecycle carbon dioxide emissions of a product. The information contains lifecycle carbon dioxide emissions from the sourcing of raw materials to the factory gate (cradle-to-gate) so that the recycling rate after use is 90 per cent (Table III).

World steel's lifecycle inventory defines fourteen steel products from different aspects:

- *Use of natural resources
- *Energy consumption
- *Environmental emissions from cradle to gate

C. Reuse System

When promoting reuse of general steel structures, it is essential to take a cross-sectional view of the construction industry and to make full use of information technology via internet. More specifically, an information network is essential to secure knowledge of the quality and quantity of reusable members as well as to provide such members of specified quality at the required locations without delay [12], [13].

TABLE III
CARBON FOOTPRINT (RUUKI.COM)

Product	CO ₂ (g/kg)
Hot-rolled steel plates and coils	710
Cold-rolled steel plates and coils	850
Colors coated steel sheets and coils	1036
Metal-coated steel sheets and coils	900
Tubular-beams, steel pipe piles and steel profiles	1070
Sandwich panels	890
Exterior wall element system	750
Hot-dip galvanized roofs, façade claddings, purlins, frames and composite beam systems	1010
Color-coated roofs and façade claddings	1150
Frames and bridge structures	1050

Material recycling will be a critical feature of sustainable development. Of all the materials used, metals have the greatest potential for unlimited recycling the elemental nature of metals means that they can virtually be reused and recycled

indefinitely without loss of their properties. The ability to recycle metals offers opportunities to conserve resources reduce energy consumption and minimize waste disposal, all of which represent important contributions to sustainable development [11]. However, it is recognized that there are practical and economic limits to the efficient collection, transportation and recovery of metals for recycling. Given that metal recycling rates tend to decrease when metal prices fall, it may be necessary to devise economic drives that encourage metal recycling when prices fall. Dematerialization will complement materials recycling and will result in smaller and lighter products with longer service lives produced with lower material and energy intensities [9].

Recycling contributes to more sustainable development by diverting materials from the waste stream and by substituting primary resources. There are different levels of recycling. Some products are recycled into new products that have exactly the same properties as the original product-this is the most environmentally beneficial form of recycling. Other products are 'down-cycled' into new products that are only suitable for lower grade applications because the recycled product has different, usually lower, material properties. Although waste is diverted from landfill by down-cycling, only lower grade primary resources are saved [13].

All new steel has a recycled content. The actual proportion to scrap in new steel is dependent upon a number of factors that include the availability and price of scrap, the production route and the specification or quality of the steel being made. Instead, designers can be confident that by specifying steel products which are over 94% recoverable and 100% recyclable, they are constructing buildings that are a valuable resource for future steel products [13].

- * Recycling reduces the need to build landfills and incinerators [9].
- * Recycling saves natural resources. When one ton of steel is recycled, for example, 2,500 pounds of iron ore, 1,400 pounds of coal and 120 pounds of limestone are conserved.
- * Recycling reduces or eliminates pollution by reducing the need to extract, move and process raw materials.
- * Manufacturing products from recycled materials saves energy.
- * Recycling reduces greenhouse gas emissions.
- * Recycling stimulates the development of green technology.

TABLE IV
RE-USE AND RECYCLING OF STEEL USED IN CONSTRUCTION [4]

Item	Structural sections	Purlins and rails	Cladding	Non-structural steel
Recycling (%)	86	89	79	85
Reuse (%)	13	10	15	2
Total (%)	99	99	94	87

More than 82 million tons of steel were recycled in the US in 2008 - more than aluminum, glass and paper combined. That steel goes back into new studs, joists, and other members used in buildings. In fact, steel is the only material with an automatic minimum default value for recycled content in the

LEED program. Further, most green codes and standards recognize the excellent potential of CFS at reducing the amount of construction waste generated at a site. Most of this is due to the almost universal use of pre-engineered and assembled panels to build steel assemblies using modern, efficient technology. For example, of all the waste from a 2000 sq. ft. residence framed with steel, less than 2 % of steel is left over and can be recycled compared to that same house built of wood generating 20% of waste that will be sent to landfill [8].



Fig. 1 A U.S. Navy assault ship built with steel from the fallen World Trade Centre (Google image)

After demolition of World Trade Center, approx. 280.000 tons of structural steel is recycled (Fig. 1).

III. STEEL BUILDINGS

The role of steel members, which in the early structures were relegated to carrying gravity loads only, has been completely upgraded to include wind and seismic resistance in systems ranging from the modest portal frame at one end of spectrum, to innovative systems involving outrigger systems, mega frames, interior super diagonally braced frames etc. at the other. Today there are innumerable structural steel systems that can be used for the lateral bracing of tall buildings (Fig. 2). It would be an exercise in futility to classify all these systems into distinct categories because there is no single creation that can be used for a comprehensive cataloging of all systems. However, for purpose of presentation, the different structural systems currently used in the design of tall steel buildings are broadly divided into the following categories roughly based on their relative effectiveness in resisting the lateral loads [23].

- * Frames with Semi-Rigid Connections
- * Rigid frames
- * Braced frames
- * Staggered truss system
- * Eccentric bracing systems
- * Interacting system of braced and rigid frames
- * Outrigger and belt truss systems
- * Framed tube system
- * The bundled tube
- * Diagrid systems
- * Hybrid System

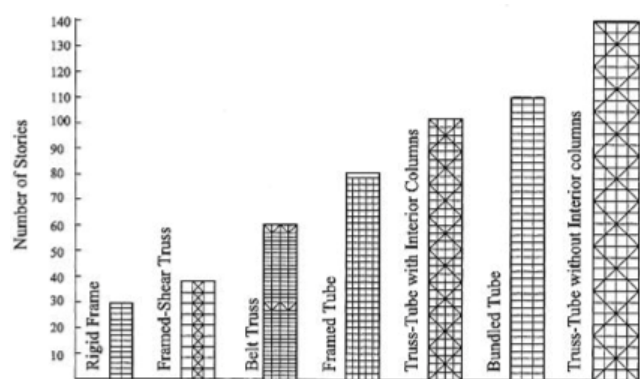


Fig. 2 Classification of steel tall buildings structure [21], [23]

A. Rigid Frames

Rigidly jointed frames or sway-frames are those with moment resisting connections between beams and columns. It may be used economically to provide lateral load resistance for low-rise buildings. Generally, it is less stiff than other systems. However, moment resisting connections may be necessary in locations where loads are applied eccentrically with respect to center line of the columns [21]-[23].

B. Braced Frames

To resist the lateral deflections, the simplest method from a theoretical standpoint is the intersection of full diagonal bracing or X-bracing. The X-bracing system works well for 20 to 60 story height, but it does not give room for openings such as doors and windows [23].

C. Staggered Truss System

In this system story-high trusses span in the transverse direction between the columns at the exterior of the building. The floor system acts as a diaphragm transferring lateral loads in the short direction to the trusses (Fig. 3) [22].



Fig. 3 Staggered truss system

D. Eccentric Bracing Systems

Eccentric bracing is a unique structural system that attempts to combine the strength and stiffness of a braced frame with the inelastic behavior and energy dissipation characteristics of a moment frame [21].

E. Outrigger and Belt Truss Systems

An efficient structural form consists of a central core, comprising either braced frames or shear walls, with horizontal cantilever “outrigger” trusses or girders connecting the core to the outer columns. In addition, a deep spandrel girder, or a “belt truss”, contributes to the structure at the levels of the outrigger (Fig. 4) [8].

F. Framed -Tube Structures

The framed tube is one of the most significant modern developments in high-rise structural form. The frames consist of closely spaced columns, 2 - 4m between centres, joined by deep girders. The idea is to create a tube that will act like a continuous perforated chimney or stack. The lateral resistance of framed tube structures is provided by very stiff moment resisting frames that form a tube around the perimeter of the building. The gravity loading is shared between the tube and interior columns. This structural form offers an efficient, easily constructed structure appropriate for high-rise buildings (Figs. 5, 6) [16], [17].

G. Braced Tube Structures

Further improvements of the tubular system can be made by cross bracing the frame with X-bracing over many stories, as illustrated in Fig. 6. This arrangement was first used in a steel structure, in Chicago's John Hancock Building, in 1969. As the diagonals of a braced tube are connected to the columns at each intersection; they virtually eliminate the effects of shear lag in both the flange and web frames. As a result the structure behaves under lateral loads more like a braced frame reducing bending in the members of the frames. Hence, the spacing of the columns can be increased and the depth of the girders will be less, thereby allowing large size windows than in the conventional framed tube structures. With this system 40 to 100 storeys building can be built [17]-[18].

H. Tube-in-Tube Structures

This is a type of framed tube consisting of an outer-framed tube together with an internal elevator and service core. The inner tube may consist of braced frames. The outer and inner tubes act jointly in resisting both gravity and lateral loading in steel-framed buildings. However, the outer tube usually plays a dominant role because of its much greater structural depth. This type of structures is also called as Hull (Outer tube) and Core (Inner tube) structures [17], [18].

I. Bundled Tube

The bundled tube system can be visualized as an assemblage of individual tubes resulting in multiple cell tube. The increase in stiffness is apparent. The system allows for the greatest height and the most floor area. This structural form was used in the Sears Tower in Chicago Fig. 1. In this system, introduction of the internal webs greatly reduces the shear lag in the flanges. Hence, their columns are more evenly stressed than in the single tube structure and their contribution to the lateral stiffness is greater (Fig. 7) [18].



Fig. 4 One Liberty Palace [23]



Fig. 5 AT&T Corporate Center [24]

J. Diagrid Systems

Another type of exterior structure is a *diagrid* system. With their structural efficiency as a varied version of the tubular systems, diagrid structures have been emerging as a new aesthetic trend for tall buildings in this era of pluralistic styles.

Early designs of tall buildings recognized the effectiveness of diagonal bracing members in resisting lateral forces. Most of the structural systems deployed for early tall buildings were steel frames with diagonal bracings of various configurations such as X, K, and chevron. However, while the structural importance of diagonals was well recognized, the aesthetic potential of them was not appreciated since they were considered obstructive for viewing the outdoors [19]. Thus, diagonals were generally embedded within the building cores which were usually located in the interior of the building. Examples are the 30 St. Mary Axe in London – also known as the Swiss Re Building (Fig. 8) [18].

K. Hybrid System

Hybrid system gaining popularity is the concrete-filled steel tube column, where the erect ability of a steel frame is maintained, but the cost effective axial load capacity of high strength concrete used. The steel tube provides confinement to the concrete much more efficiently than normal reinforcement does, and it is on the extreme outside, where it is most effective (Figs. 9, 10) [23].



Fig. 6 Guardian B. [20]



Fig. 7 Sears Tower [21]



Fig. 8 Swiss re B. [22]



Fig. 9 Citicorp T. [22]



Fig. 10 Overseas Union T. [22]

IV. CONCLUSION

Steel structures have many advantages; they are lightweight, they provide material efficiency and are mostly produced out of site. The load of weight required to be

transferred is less in comparison with reinforced concrete or masonry systems. Steel elements are prefabricated which facilitates construction. Time period needed to provide air tightness within façade coatings made of steel materials can be decreased by 20% when compared to the bricks and block construction. Some of the most important advantages are the material characteristic features of steel. Steel is a recyclable material contributing in ecological design. Using steel at tall buildings has many advantages such as lightness, reuse and recycling etc. Also, steel enables construction with different tall building structural systems.

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