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Keynote Paper

Steel and Composite Structures: Key challenges and trends for the future

*Brian Uy[1)]

[1)] *School of Civil Engineering, The University of Sydney, Sydney 2006, Australia*
[1)] *brian.uy@sydney.edu.au*

ABSTRACT

Steel and steel-concrete composite structures have formed an important part of civil engineering infrastructure for over a century. This is best evidenced by the world's tallest buildings and longest span bridges all employing innovations in steel or steel-concrete composite structures. This paper will review recent major innovations that have allowed for the promulgation of steel and steel-concrete composite solutions. Projections and forecasts on future uses will also be provided. The paper will also acknowledge some of the impediments that are being posed to the use of steel and steel-concrete composite structures and how individual solutions for materials can be addressed to ensure that their use continues to thrive for the future. The paper posits that the future of steel and composite structures lies in the intersection of the development of high performance steel (HPS) and high performance concrete (HPC) and in concert with design for manufacture (DfM) sustainability principles.

1. INTRODUCTION

Steel and composite structures as we know them today have been utilised for over 150 years, with steel being manufactured in an industrialised process using the Sir Henry Bessemer process since the mid 19th century. Concrete or steel reinforced concrete evolved also during the mid 19th century with iron reinforced concrete proposed by Coignet and Monier in France. Composite structures came about rather serendipitously when concrete was used predominantly for fire resistance purposes in steel buildings at the turn of the 19th and 20th century when the concept of the skyscraper evolved. Steel strengths over the 150 years have increased by an order of magnitude, with typical tensile yield strengths ranging from 200 MPa during the industrial revolution to strengths of up to 2000 MPa now being achieved for sheet steels in the automotive industry. Furthermore, concrete strengths have also evolved and increased in strength by an order of magnitude over this period, with concrete compressive strengths ranging from 20 MPa which is widely regarded as structural

[1)] Professor

concrete to compressive strengths of up to 200 MPa for modern reactive powder concretes. The benefits of composite structures have always been founded in the juxtaposition of concrete with steel to allow both materials to be used in their optimum mode. Steel has high tensile strength and when used in compression in thin sections can have its local and overall stability improved by the juxtaposition of concrete to arrest the local and global instabilities. Concrete is best utilised in compression and can be significantly improved by the use of reinforcing steel, prestressed or post-tensioning steel or by the use of steel to confine concrete in a core to achieve its optimal compressive strength. A modern day iconic example of the use of steel and composite construction is evident in the construction of The Shard, London, see in Figure 1.

Fig. 1 The Shard, London, United Kingdom

2. KEY CHALLENGES

There are many key challenges facing the civil engineering and construction industry. The most obvious challenge in modern society is the increased urbanization of the world's population. This explosion in growth in cities and megacities around the world has put a strain on higher density living and office environments. Thus, the ability to build taller builders is not only a challenge but an increasing necessity. The international trend in tall building construction is to use composite, steel or mixed systems which is now prevalent in 70% of 100 of the world's tallest buildings, (Council on Tall Buildings and Urban Habitat, 2018). Furthermore, many of the world's longest bridges employ the use of steel or composite techniques. The key challenges in buildings and bridges are to achieve higher performance structures, with higher strength to weight ratios coupled with optimal durability.

Fig. 2 Erasmusbrug, Rotterdam, Netherlands

3. TRENDS FOR THE FUTURE

The prevailing trends in the civil and structural engineering industry include some of the following key issues:

- Design for manufacture (DfM);
- Sustainability principles, using the (4R's) *Rethink, Reduce, Reuse* and *Recycle*
- The development of high performance steels (HPS);
- The development of high performance concretes (HPC with cement replacement);

DfM has been of significant interest in the building and civil engineering sector for a number of decades. DfM allows builders and contractors to manufacture building components off site and can reduce workforce on site. This has significant benefits in terms of labour cost and safety. An iconic steel and composite structure, Leadenhall building in London used significant amounts of DfM techniques with the use of prefabricated structural steel and precast concrete as illustrated in Figure 3.

Fig. 3 Leadenhall building, London, United Kingdom

Sustainability principles and the concepts of 4R's do lend themselves to steel and composite solutions. The *Rethink* concept in steel and composite structures is often at the concept stage. Steel and composite buildings are often being designed with future use and adaptability in mind. The ability to *Rethink* how a structure is constructed and deconstructed can often have significant environmental benefits over the life of a project. Composite structures by their very nature employ the concept of *Reduced* materials as the use of composite construction ultimately results in a reduced steel section size. The steel industry is moving toward the concepts of *Reuse* in great leaps and bounds and structural steel is able to be 100% reused which is in stark contrast to concrete construction. A seminal document has been published by the Steel Construction Institute in the United Kingdom that is leading the way internationally for steel to be reused from construction projects, (Steel Construction Institute, 2019). Finally structural steel has the ability to be 100% *Recycled* and this usually will be used for the production of reinforcing steel to be used in reinforced concrete which can form part of composite structures. The following two subsections of High Performance Steels (HPS) and High Performance Concretes (HPC) will be covered individually in depth.

4. HIGH PERFORMANCE STEELS (HPS)

High performance steel has the potential to significantly revolutionise the construction of civil engineering infrastructure. For the purposes of the discussion, the following nomenclature is used:

- High strength steels, (steels of ultimate tensile strength between 500 to 700 MPa)
- Ultra high strength steels (steels of ultimate tensile strength of 1000 MPa)
- Stainless steels (austenitic and duplex steels with strengths up to 700 MPa)
- Clad steels (mild structural steels clad with a layer of titanium or stainless steel)

High strength steels have been used in practice for over two to three decades with fabricated quenched and tempered structural steels being used particularly in iconic structures. Recent research has been carried out to further optimise high strength steel sections for use in composite sections, (Huang et al., 2019) as illustrated in Figure 4.

Fig. 4 High strength steel slenderness tests, (Huang et al, 2019)

Ultra high strength steels have been in existence for many years and have often been used in defence and mining applications. Furthermore, developments in the automotive industry can produce steels up to 1500 MPa. Ultra high strength steels of ultimate yield strength of 1000 MPa using fabricated techniques can now be produced for civil and structural engineering applications. Recent research has been carried out to optimise ultra high strength steel sections for use in composite sections, (Li et al., 2019).

Fig. 5 Ultra high strength steel slenderness tests, (Li et al, 2019)

Stainless steels can be mainly categorized into austenitic and duplex tyoes. Austenitic stainless steels, whilst having superior high temperature behaviour and corrosion resistance generally have tensile strengths typical of mild structural steels. Duplex stainless steels generally achieve much larger yield strengths of 600-700 MPa and economical forms are also being proposed known as lean duplex. Recent research has been carried out to establish slenderness limits for stainless steel fabricated sections, (Kazemzadeh Azad, Li and Uy, 2019).

Fig. 6 Stainless steel slenderness tests, (Kazemzadeh Azad, Li and Uy, 2019)

Clad steels have also been existent for many years and have mainly been used in the food, petrochemical and shipping industries, however future developments may see them gain favour for use in civil and structural engineering applications.

5. HIGH PERFORMANCE CONCRETES (HPC)

High performance concrete (HPC) generally relates to concrete with improved compressive strengths and durability characteristics. Concrete strengths can be produced up to 200 MPa, typically known as reactive powder concrete. One of the biggest impediments to concrete for the future is the resistance to the use of cement in concrete, given its significant perceived carbon dioxide emissions that are given off in the production of cement clinker. Geopolymer concretes have had significant development over recent decades and the ability to be able to produce high strength and durable concrete will be a focal point of future research. Recent research to establish stress-strain characteristics of geopolymer concretes has been carried out, (Noushini et al, 2016).

6. FUTURE OF STEEL AND COMPOSITE STRUCTURES

Given the future trends in HPS and HPC are the driving forces behind the DfM and 4R principles, the area of composite structures certainly lends itself to innovative solutions that bring all these principles together. Figure 7 highlights where the future of steel and composite structures research should be focused for the future for greatest impact.

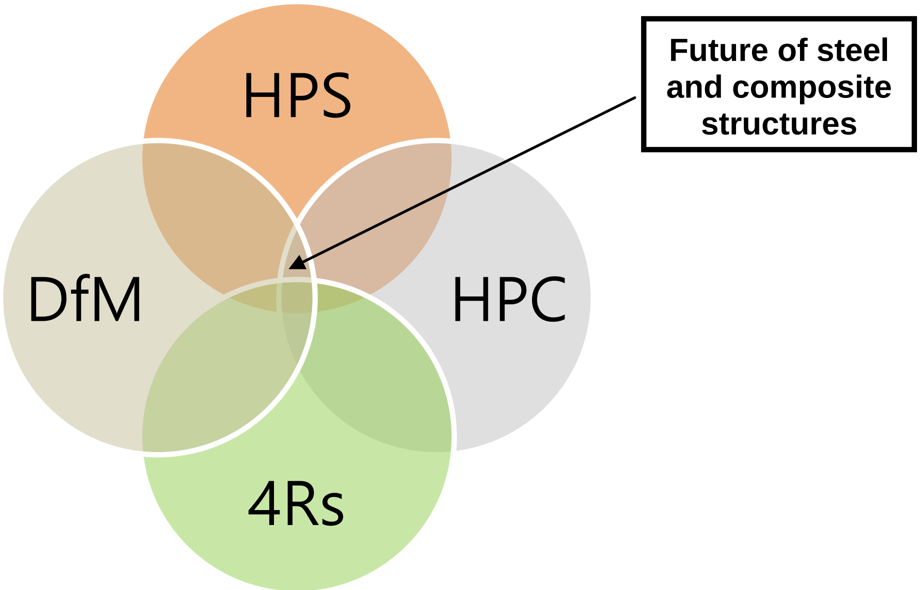

Fig. 7 Future research challenges for composite structures

7. CONCLUSIONS

This paper has highlighted the key challenges and trends for the future for steel and composite structures. The issues of DfM, 4Rs, HPS and HPC have been addressed. Ongoing work in the area of HPS has been outlined as has the important work in Geopolymer concretes. These four areas and their intersection points give a futuristic insight into what areas of research will be important for the future. The scientific advances in HPS and HPC development coupled with the construction sectors move toward DfM and the socio-political moves toward 4Rs gives the best forecast for research in steel and composite structures for the future.

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