

Material Follows Function: Nanotechnology and Sustainability in Steel Building Constructions

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Abstract: *Nanotechnology has introduced different manipulation processes on materials used in building construction. These processes are in order to enhance the existed materials, creating desirable properties, and improving environmental effects of construction industry. It seems we can now use the slogan “Materials Follow Function” and in this paradigm, construction industry can experience phenomenon other than its conventional one. In this research, enhancements in steel, as a major construction element, with the help of nanotechnology have been investigated. Strength, corrosion resistance, heat-affected zone, and fatigue are the enhanced properties of steel which are probed in this research. After showing the advantages, disadvantages or affairs that need special concern have been discussed. Finally, the parameters of sustainability in steel constructions in which nanotechnology is used are evaluated.*

Keywords: Nanotechnology, building, steel construction, sustainability.

1. Introduction

Beside some ancient antiques that has special characteristics for the distribution of nano-particles due to the fabrication process like The Lycurgus cup, Maya Blue, and Damascus steel swords, the origins of nanotechnology goes back to the lecture of the physicist Richard P. Feynman, with the lecture at the California Institute of Technology entitled “There’s plenty of room at the bottom” [1]. The conference of Norio Taniguchi on nanotechnology in 1974 [2], the article of Eric Drexler in 1980s, and his published doctoral thesis [3] were other important published work in this field after the aforementioned conference.

Now we have different researches on this field as The U.S. National Nanotechnology Initiative (NNI) outlay on nanotechnology is more than \$1 billion per year [4]. Consequently, we have seen the development of the usage of nanotechnology in recent two decades and as experts in nanotechnology believe, it has the potential to create new horizons for the human world after the advent of steam engines and Information Technology (IT) [5].

Nanotechnology is the manipulation of matter on an atomic and molecular scale with the use of small particles (with at least one dimension from a few nanometers to 100 nanometers) either to improve the characteristics of a material or to create new material with novel materials for meeting desired trait. Due to the great changes with manipulation of a material in nanoscale, it is important to be concerned. This event is because the characteristics of materials has not linear trait from macro to nanoscale. In the former we are faced with familiar features of materials, but in the latter, different things start to happen as in this scale gravity becomes unimportant and we face quantum effects [6].

Nanotechnology is dominated by development of basic physics and chemistry research [7] and is used in different areas like surface science, organic chemistry, medicine,

semiconductor physics, molecular biology, aerospace industry, material Science, and construction.

There are different areas in the use of nanotechnology in construction [8]-[11] with the focuses like Lighter and stronger, low maintenance coating, enhancement in cementitious materials, fire retardants, insulations, nanosensors in construction [12]. Also, different researches on its infrastructures have been the focus of investigations [13]. Health related to construction can be added to above features. Therefore, there is a great concern in Leadership in Energy and Environmental Design (LEED), Green Star (Australia) accreditations [14] for nanotechnology in construction.

Moreover, as our built environment consumes almost 40% of global energy which would result in the emission of 30% of global greenhouse gases [15], human built constructions are important items for environmental features. Based on nanoscience different products have been propounded to enhance the constructional materials. These materials affect the sustainability of the building and should be considered.

Steel is an important material in building construction. More than half of the global steel production goes to construction [16]. This shows the necessity of steel concerns in construction.

In this research, after a brief history of steel constructions, the advantages of the usage of nanotechnology in these constructions are investigated. After that, the disadvantages and possible problems of using nanomaterials are discussed. Finally, in section 5, the sustainable characteristics of steel construction with the use of nanotechnology are probed.

2. Steel

Iron and its alloys have been an important component in building construction. The previous usage of it was in four major forms. Wrought iron which was used from 18th

century is tough, malleable, ductile and easily welded due to the low (0.1 to 0.25) carbon content. Eiffel tower is built with some form of wrought iron. It was considered pure iron with the standards of the time. However, with today standards the pure iron carbon content should not exceed 0.008 wt% [17].

The other form is cast iron. Although it was used from 9th century in Pagodas in China, the prevalent use of it was in 19th century and after the Industrial Revolution when it was cheap and more available. As an example of the causes of being more available Bessemer process can be mentioned that propounded the industrial process for the mass-production of steel in 1855. The larger amount of carbon (more than 2.1%) creates a harder and stronger type of iron. But increasing the hardness with increased carbon leads to have less ductility. Less ductility is the reason to build constructions with casting. Sheet iron is thin flat pieces of iron and was used from 19th century. Steel was introduced in late 19th century. Steel is an alloy of iron and other elements. The carbon content of steel is from 0.002% to 2.1% by weight. Beside iron and carbon, manganese, phosphorus, sulfur, silicon, and traces of oxygen, nitrogen and aluminum are among the elements in steel. Also, for improving its specifications, other elements like nickel, manganese, chromium, molybdenum, boron, titanium, vanadium and niobium would be added to steel [18].

As a wide industry that has exceeded 1.5 billion tons of crude production [19], steel needs further investigations to be enhanced and had less deficiencies. Furthermore, although this industry has met some factors of sustainability, it can be improved to have lower embodied energy with augmentations for lowering its raw material and therefore lower energy consumption in its excavation and processing.

3. Advantages of Nanotechnology in Steel

Nanotechnology has propounded different strategies to improve steel properties. Some of these properties contain strength, corrosion resistance, resistance of affected area by welding and its heat, and enhancing the fatigue problem in steel structures.

3.1 Strength

Strength is among pivotal properties of structural materials. Therefore, elevating the strength of steel can enhance its function to a considerable extent. Nanotechnology has proposed enhancement methods in strength of steel products like cables and bolts which can lower the material usage and therefore lower the total energy embodied in a structure.

High strength joints are indispensable part of a structure. Bolts are important element in joints. Because of the fact that a small amount of hydrogen embrittlement in steels that exceeded tensile strength of tempered martensite of 1200 MPa would be the cause of the failure of the structure (delayed fracture), steel bolts highest strength have been limited to around 1000 to 1200 MPa. The researches have showed vanadium and molybdenum nanoparticles can be the

cause of lessening the delayed fracture by improving the microstructure of the steel and reducing the effect of hydrogen embrittlement.

The other example of higher strength in steel with the help of nanotechnology is high strength cables. Cables produced by the refinement of the cementite phase of steel to a nano-size are stronger and would reduce the materials in suspension bridges and precast concrete.

It should be mentioned that although carbon nanotubes (CNT's) is great properties for toughness and strength, because of its slipperiness nature and due to the graphitic nature, it cannot be bind well with steel. Also, the temperature in steel manufacturing can affect the CNT properties [6].

3.2 Corrosion resistance

Two kinds of products, both with corrosion resistant property but with different mechanical properties, are now available. One of them is Sandvik Nanoflex, and the other one is MMFX2. One of the attempts in producing low carbon, high-performance steel (HPS) for bridges has been done in 1992 [20] with the help of nanoparticles to enhance corrosion-resistance feature and weld ability of steel [12]. A new stainless steel with ultra-high strength and good formability is Sandvik Nanoflex [21]. This product can have a lighter weight than aluminium and titanium because of its ultra-high strength and modulus of elasticity [12]. The aforementioned characteristic in addition to its resistance in corrosion has made it as an efficient element. This product have both of the desirable characteristics for steel which are strength and ductility [6]. MMFX2 is another kind of steel with modification in nanoscale that is three times stronger than normal steels. Its corrosion resistance and strength can put it as an alternative for the use in reinforced concrete in high risk environments where stainless steel is usually used [12].

3.3 Heat Affected Zone

The heat-affected zone (HAZ) is the affected area of base material in microstructure scale by welding or heat intensive cutting operations and has the reverse relation to thermal diffusivity. Welds and HAZ can brittle and fail under dynamic loadings like earthquake. Therefore, we see oversizing of structures in order to prevent HAZ failures [6]. One of the propounded methods for increasing the toughness of welds is the addition of nanoparticles of magnesium and calcium makes the HAZ grains finer in plate steel [6]. Based on this method there is no need to oversize the structure for HAZ and therefore would have diverse beneficial factors.

3.4 Fatigue

Fatigue is the progressive and localized structural damage that occurs under repeated loading and unloading. This can happen at stresses that are drastically lower than the yield stress of the material. It is obvious that this feature can shorten useful life of the structure. There have been different

researches on this category from 1837 when Wilhelm Albert publishes the first article on fatigue [22].

There are numerous failures in constructions like bridges and transportation vehicles that are caused directly or indirectly by fatigue. Inhibition of crack initiation and crack propagation are essential for fatigue properties improvement [23]. Each one needs their own scale for consideration. Crack propagation depends on micro-order structures like grain boundary and the texture; but, crack initiation depends on nano-order structure like precipitation, slip, and dislocation motions [23].

Cu precipitates have different crystal structures depending on their size; body-centered cubic (bcc or cI) [24] structure for diameters smaller than about 4 nm and face-centered cubic (fcc, cF or ccp) [24] structure for larger diameters. Precipitation strengthening in steels from copper rich body-centered cubic (bcc) precipitates has been researched from Russel and Brown paper [25], [26]. As the low solubility of Cu in Fe at low temperature, the process would be applicable by thermal aging. Although Mn, Cu, Ni, Cr, Mo, Nb etc. would be added to steel to reach at the desired properties, as copper as it contributes to strength through the precipitation hardening process, it plays an essential role in obtaining very high strength level like 550 MPa in HSLA-80 and 690 MPa in HSLA-100 [27], [28].

As a phenomenon utilized in the design of some High-Strength Low-Alloy (HSLA) steels, precipitation of copper and associated property changes during aging of three Cu-containing HSLA steels has been investigated. The results showed that the precipitation occurs in two steps with the activation energy in the range of 114–128 kJ/mol and 64–77 kJ/mol. The first one is much lower than 284 kJ/mol required for diffusion of copper in ferrite, indicating the dominant influence of high density of dislocation in the quench matensite matrix on the diffusive mass transfer during aging. The second one with 64–77 kJ/mol activation energy can be described as the diffusion of carbon in ferrite during tempering of the HSLA steel in presence of the lattice defects. The peak hardness during isothermal aging was achieved in the 500–550°C aging temperature range [27].

Small coherent bcc (smaller than 4 nm) precipitates are responsible for the strengthening of the reactor pressure vessels (RPV) steel, working as obstacles to dislocation motion. [29]. Investigations shows that distribution of hardening behavior is related to Cu particles. Cu clustered and precipitated more finely in deformed ferrite than in simple ferrite [30]. Addition of nano particles of copper not only helps strengthening of steel, but also causes the steel to maintain its structural integrity up to about 540°C. This is an improvement in steel temperature restriction which regular steel starts to lose its structural integrity above 400°C and lost half of its strength at 600°C. Figure 1 shows the effect of heat treatment temperature on fatigue strength at 2×10^6 cycles of two investigated steel with specification showed in Table 1. As depicted in Figure 1, regardless of allotropies with different heat treating, fatigue strength of steel with higher amount of Cu is higher than the other one.

4. Disadvantages of nanotechnology in steel

Nanotechnology with its all benefits consumes great amount of energy for production at this time. High energy consumed in construction industry shows the higher embodied energy for this technology [12]. Therefore method of construction and manufacturing of nanotechnology products can be among the most imperative items for investigation. Also, the long term environmental effects of nanotechnology are another item that should be concerned. Although the most uses of nanotechnology in buildings are proved to be harmless, we now know the problem that nanotubes can make lung problems. Therefore, at least workers whose job is involved with this material are in danger.

More investigations would show the possible long term or short term dangers of these materials and would the matter of diverse researches as there are different organizations with the purpose of health considerations and nanotechnology. For instance, Nanotechnology Environmental and Health Implications (NEHI) is responsible for the Federal program that oversees nanotechnology R&D [31].

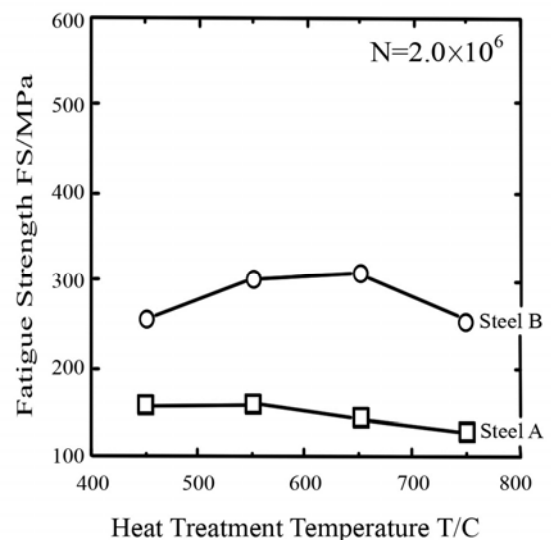


Figure 1: Effect of heat treatment temperature on fatigue strengths at 2.0×10^6 cycles of the two investigated steels by Yokoi and Maruyama [23].

Table 1: Chemical compositions of two investigated steels [23]

Steel	A	B
C	0.0018	0.002
Si	0.01	0.01
Mn	0.2	0.2
P	0.004	0.004
S	0.004	0.004
Al	0.04	0.04
Ti	0.05	0.05
N	0.0016	0.0016
Cu	<0.002	1.51

5. Sustainability and Nanotechnology

Sustainability can be described as an approach for meeting our today requirements without lessening the future generation ability to acquire their requirements by the aforementioned resources. It is an approach for using the least non-reusable energy sources [32].

One of the resources is natural material resources. Many of these materials take many decades to go back to the nature. Also, by overusing the natural material resources we may cause shortage in material for future generations. Hence one of the best solutions for preventing the shortage in materials for next generations is to lower the consumption of today. As the requirement is fixed, the point would be at using materials with higher efficiency in order to reduce the need for further material. Nanotechnology plays an important role in this case. It can alter materials properties by the manipulation of their nanoscale structure which can lead to stronger materials with higher desirability which leads to lower consumption.

The aforementioned reduction is not only in using natural resources. The lower material requires lower transportation, human resource energy, mechanical devices, and the related pollutions. Therefore the life time energy embodied of the construction would reduce in a considerable amount. The process of reusing or recycling of materials produced by nanotechnology should be carefully investigated in order to have a comprehensive view of long and short term environmental effects of these materials. Nanotechnology would change the economical system. For having a stable economical growth for each local region, policies should program related plans in order to escape from the possible problems.

6. Conclusion

Nanotechnology is the manipulation of materials in atomic and molecular scale for either improving the properties of a material or creating new materials with desired characteristics. Steel has been the focus of these researches with improving its strength, corrosion resistance, fatigue, and HAZ phenomenon.

Nanotechnology makes the material consumption lower that can be the cause of lower energy and material consumption by improving materials strength or other desirable properties like insulation etc.; but, the investigations for lowering the energy embodied in production phase can enhance its sustainability.

There are different categories that need further investigations. Long-term and immediate environmental effects of nanotechnology are among these affairs that should be meticulously scrutinized. Also, recycling techniques should be considered more to guarantee the lowest effects for future generations. Furthermore, researches on the process of manufacturing can help to have lower cost nanotechnology based materials with lower embodied energy.

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