International Journal of Innovative Research in Computer Science & Technology (IJIRCST)
ISSN: 2347-5552, Volume-10, Special Issue-3, March-2022
Young Researchers' Conference on Indian Literatures, 2022
Organized by Presidency University, Bangalore, India

Structure of Ferrous Metals: Exploring Iron-Based Alloys

Mr. Medikeranahalli Santhosh
Assistant Professor, Department of Civil Engineering, Presidency University, Bangalore, India,
Email Id-santhoshmb@presidencyuniversity.in

ABSTRACT:

Iron and carbon alloys play a significant part in modern civilization, finding use in a variety of sectors ranging from construction to the production of automobiles. Because of their remarkable mechanical qualities, such as great strength, endurance, and malleability, ferrous metals are used widely. Due to their remarkable mechanical qualities and affordability, ferrous metals, which predominantly consist of iron and carbon alloys, are extensively used in a variety of sectors. The overview of ferrous metals in this document includes information on their main characteristics, uses, and potential environmental effects. This chapter seeks to improve comprehension of ferrous metals and their importance in the engineering and manufacturing industries through a review of the literature.

KEYWORDS:

Application, Cast Iron, Ferrous Metals, Iron, Pig Iron, Structure.

I. INTRODUCTION

Ferrous metals, usually referred to as iron-based metals, are a class of metals with distinctive characteristics and uses that are predominantly made of iron. These metals have been utilized by humans for thousands of years and are essential to many different industries. This essay will examine ferrous metals, including their varieties, properties, production processes, and important uses. Iron content in ferrous metals is often more than 50% by weight. Their characteristics can be changed by the addition of other elements including carbon, manganese, chromium, and nickel. These substances contribute advantageous properties including strength, hardness, and corrosion resistance. Ferrous metals are useful for a variety of applications because of their long lifespan and propensity to sustain severe loads. The most popular ferrous metals are cast iron and steel, however there are other varieties as well. Cast iron is brittle and more resistant to wear and deformation than steel because it has a greater carbon content. It is frequently employed in structures like engine blocks, pipelines, and building materials where strength and resistance to compression are essential requirements. Contrarily, steel is an iron and carbon alloy that normally has less carbon than cast iron. It has a wide range of characteristics based on its makeup and is quite adaptable.

Steel may be further divided into a number of subcategories, including alloy, carbon, and stainless steel. The most fundamental type of steel is carbon steel, which finds extensive usage in the mechanical, automotive, and construction sectors. In applications such as cookware, medical equipment, and construction where toughness and hygienic design are priorities, stainless steel is frequently used because it includes chromium, which offers high corrosion resistance. Alloy steel is used in applications in the aerospace, automotive, and tool manufacturing sectors because it combines different elements to improve certain attributes including strength, toughness, and heat resistance. The extraction, refinement, and processing of ferrous metals are only a few of the processes used in their manufacturing. The main source of iron is iron ore, which is extracted from the soil and put through a number of procedures to extract the metal.

The ore is initially crushed, and then it is refined to eliminate impurities using procedures like smelting and purifying. To get the necessary characteristics, the resultant iron is further treated. For instance, whereas other elements can be alloyed to form certain types of steel or iron alloys, carbon is added to produce steel [1], [2]. Due to their beneficial qualities, ferrous metals are used in a variety of sectors. Steel is widely used in the infrastructure and construction industries because of its durability, ductility, and adaptability. Roads, bridges, and other structural elements are made of steel. Due to their durability and resistance to impact, ferrous metals are used often in the automobile industry to produce parts for engines, chassis, and bodies. Ferrous metals are also extensively employed in the production of machinery, tools, appliances, and transportation technology. The lifespan of ferrous metals includes extensive recycling.

Recycling helps to protect natural resources and cut down on energy use and greenhouse gas emissions. It is possible to recycle scrap metal, including old steel and iron goods, and utilize it to make new ferrous metals. Sorting, shredding, melting, and purifying the waste metal are all steps in the recycling process before it is utilized to create a variety of goods. To sum up, ferrous metalswhich are mostly made of iron and may also contain other elementspossess desirable qualities including strength, durability, and corrosion resistance. The most popular ferrous metals are cast iron and steel, with steel being particularly adaptable since it can be alloyed and customized for certain needs. Construction, automotive, manufacturing, and other sectors use ferrous metals extensively. Recycling is essential to the long-term viability of the extraction, refinement, and processing processes used to produce ferrous metals. Ferrous metals will continue to be crucial components for the advancement of society as industries and technology expand [3], [4].

Properties of Ferrous Metals: Iron and different alloying elements make up ferrous metals, which have a variety of qualities that make them appropriate for a variety of uses. Ferrous metals have the following important characteristics:

a. **High Strength:** Ferrous metals have a high strength that allows them to sustain high pressures and weights. In applications where structural integrity is crucial, such as in the construction, automotive, and equipment sectors, this feature is particularly significant.

b. **Durability:** Ferrous metals are renowned for their long-lasting performance and durability. They are resistant to abrasive environmental elements including corrosion, high temperatures, and wear. Their widespread usage in applications that demand resistance to outside pressures and environmental variables is a result of this feature [5], [6].

c. **Magnetic Properties:** The majority of ferrous metals have magnetic characteristics, especially steel and iron. They can be utilized in things like electric motors, generators, transformers, and magnetic storage systems thanks to this property.

d**. High Melting Point:** Ferrous metals often have high melting points, which allow them to resist high temperatures without experiencing substantial deformation or structural damage. In applications that entail exposure to heat, such as the manufacture of industrial machinery, furnaces, and high-temperature tools, this feature is crucial [7], [8].

e. **Ductility:** Ferrous metals are ductile, meaning that they may be easily molded and moulded using a variety of production techniques. They have high ductility, which enables them can be bent and stretched into various forms without snapping or losing their strength. Applications that need for delicate and sophisticated components, like those in the automotive and aerospace sectors, depend heavily on this feature.

f. **Corrosion Resistance (Stainless Steel):** The presence of chromium gives stainless steel, a particular type of ferrous metal, remarkable corrosion resistance. On the metal's surface, the chromium creates a thin, protective oxide coating that shields it from rust and corrosion. Due to its resistance to moisture, chemicals, and oxidation, stainless steel is widely sought-after in applications such as cookware, medical equipment, and maritime conditions.

g. **Recyclability:** Ferrous metals may be recycled quite easily. They retain their quality and qualities after being melted down and repurposed. In addition to protecting natural resources, recycling ferrous metals also uses less energy and emits fewer greenhouse gases.

The precise characteristics of ferrous metals can change based on their composition, alloying components, heat treatment, and manufacturing procedures, it is crucial to keep in mind. These differences enable the creation of a large variety of ferrous metal alloys that are customized to certain purposes, thereby increasing their applicability across several sectors [9], [10].

II. DISCUSSION

Production Process of Ferrous Metals: The extraction, refinement, alloying, and shaping steps are all part of the manufacture of ferrous metals. An overview of the common production procedures used to make ferrous metals is given below:

a. **Extraction:** Iron ore is taken out of the Earth's crust as the initial stage in the manufacturing of ferrous metals. Hematite, magnetite, and taconite are just a few of the several iron-containing minerals that may be found in iron ore. The ore is removed using open-pit or underground mining techniques.

b. **Crushing and Grinding:** Following extraction, the iron ore is broken down into tiny pieces by crushing and grinding. This method makes it easier to separate the desirable iron ore from the undesirable gangue minerals.

c. **Beneficiation:** Crushed iron ore is subjected to beneficiation procedures in order to reduce impurities and raise the iron content. The iron ore is separated from impurities like silica, alumina, and phosphorus using methods including gravity separation, magnetic separation, and flotation.

d. **Smelting:** Iron is extracted from concentrated ore by the process of smelting. Limestone serves as a flux while coke, a kind of carbon, acts as a reducing agent when combined with iron ore in a blast furnace. The iron ore is converted to molten iron, or pig iron, as well as byproducts like slag, in the blast furnace's extreme heat.

e. **Refining:** Pig iron must be refined because it is impure and has too much carbon, silicon, sulfur, and other impurities. To achieve pure iron, the refining procedure entails eliminating these impurities. Usually, electric arc furnaces (EAF) or the basic oxygen steelmaking (BOS) method are used to accomplish this.

f. **Alloying:** Alloying elements are added to ferrous metals throughout the refining process to improve their characteristics. To attain desired properties like improved strength, hardness, corrosion resistance, or heat resistance, alloying elements like as carbon, manganese, chromium, nickel, and others are added in particular proportions. These elements can be added to iron to create different kinds of steel or iron alloys.

g. **Casting or Forming:** When the required composition is reached, the molten metal is cast into different shapes. To form the required shape, molten metal is poured into molds during casting. Sand casting, investment casting, and die casting are all casting techniques. Alternatively, depending on the ultimate product needed, the molten metal might be shaped by procedures like rolling, forging, extrusion, or stamping.

h. **Heat Treatment:** Annealing, quenching, and tempering are a few heat treatment techniques that may be used to change the characteristics of ferrous metals. Heat treatment requires carefully controlling the heating and cooling of the metal in order to change its microstructure, which affects the metal's hardness, toughness, and other mechanical qualities.

i. **Finishing Procedures:** To obtain the desired surface finish and dimensional precision, the ferrous metal products may go through further finishing procedures after shaping and heat treatment, such as machining, grinding, polishing, and coating.

It is significant to note that the particular manufacturing procedures might change based on the type of ferrous metal being produced and the intended use. The quality and variety of ferrous metal goods on the market are largely due to the efficiency and precision of these processes, which are continually improved by technological and manufacturing developments.

Structure of Ferrous Metal: A class of metallic substances known as ferrous metals is composed mostly of iron. Due to their desired qualities, including high strength, outstanding magnetic characteristics, superior machinability, and relatively low cost, they are widely employed in a variety of sectors. Predicting the behavior and characteristics of ferrous metals requires an understanding of their structure. We shall go into great detail on the crystal structure, phases, and microstructures of ferrous metals in this post. Most ferrous metals have a body-centered cubic (BCC) or face-centered cubic (FCC) crystal structure. Temperature-dependent allotropic transformations may be seen in pure iron. Alpha-iron, sometimes referred to as ferrite, is the BCC structure that iron adopts below 912 degrees Celsius. Iron changes into the FCC structure known as gamma-iron or austenite above this temperature. The Curie temperature describes the transition between these two phases.

Carbon is one alloying element that may be added to materials to change their crystal structure and create new phases. Inferred from the structure of ferrous metals, carbon is important. It may dissolve in both ferrite and austenite when present in tiny amounts, producing a solid solution. The temperature and chemistry of these phases affect how soluble carbon is in them. Because ferrite can only dissolve a finite amount of carbon at low temperatures, cementite (Fe_3C) is the result. Iron alloys' strength and hardness are enhanced by cementite, which is very hard and brittle. In ferrous metals, ferrite, austenite, and cementite work together to generate a number of significant microstructures. Pearlite, a lamellar combination of ferrite and cementite, is one example of this type of microstructure. When austenite undergoes a eutectoid transition and cools below the eutectoid temperature, pearlite is created. It is a typically present microstructure in steels and is generally soft and ductile. Martensite is yet another microstructure frequently seen in ferrous metals. Rapid quenching of austenite results in the creation of martensite, which encourages a diffusionless transition by blocking carbon atom diffusion. Martensite is exceedingly hard and brittle with a severely deformed BCC structure. Its creation may be influenced by changing the rate of cooling while undergoing heat treatment, which makes it possible to manipulate mechanical characteristics.

Other microstructures seen in ferrous metals besides pearlite and martensite include bainite, tempered martensite, and numerous secondary phases. Between the temperatures needed for the creation of martensite and pearlite, bainite can be found. It is made up of ferrite mixed with bainite carbide, a meta-stable form of Fe3C. A nice balance of strength and hardness may be found in bainite. Martensite that has been reheated and allowed to partially change into a cementite and ferrite combination is known as tempered martensite. This procedure makes martensite less brittle and increases its toughness. Carbides, nitrides, and intermetallic complexes can all be secondary phases in ferrous metals. These phases can develop as a result of heat treatment, solidification, and cooling operations. Depending on their composition, size, and distribution, they may have an impact on the material's mechanical, chemical, and physical characteristics. In conclusion, the crystal structure, phases, and microstructures of ferrous metals have an impact on their structure. BCC and FCC are the two main crystal structures, and depending on the temperature and alloy content, several phases can exist. Cementite is created as a result of the addition of carbon and can exist independently or as a component of other microstructures. Important microstructures with distinct mechanical characteristics include pearlite, martensite, bainite, and tempered martensite. To modify the characteristics of ferrous metals to fulfill particular application needs in sectors ranging from construction to automotive and beyond, it is crucial to comprehend and regulate their structures and phases.

Iron: The chemical element iron has the atomic number 26 and the symbol Fe. One of the most prevalent and often utilized metals in the world. Iron is a member of the transition metal family and is renowned for its durability, malleability, and electrical conductivity. Iron is a soft metal that appears silvery-gray when it is pure. However, because of its propensity to corrode, it is rarely utilized in its pure form. Instead, to improve its characteristics, iron is frequently alloyed with trace quantities of carbon and other metals. Iron is a crystalline substance with a body-centered cubic (BCC) crystal structure. Pure iron changes phases at normal temperature, transitioning from face-centered cubic (FCC) gamma-iron, also known as austenite, to BCC alpha-iron, popularly known as ferrite, at about 912 degrees Celsius. The Curie temperature is the precise temperature at which this phase shift takes place, and it is reversible.

At around 1,535 degrees Celsius for its melting point and 2,750 degrees Celsius for its boiling point, iron has a high melting point. It has ferromagnetic characteristics, which allow it to be magnetized, and is a good conductor of electricity. When carbon is added to iron, many iron alloys are created that are all referred to as steel. Steel can include anywhere from a few tenths of a percent to several percent carbon. Iron gains extra strength and hardness from the addition of carbon, improving its suitability for a variety of uses.

Steel is the most common type of iron alloy, and due to its flexibility, it is essential in sectors including construction, appliance production, car manufacturing, shipbuilding, and ship repair. Based on the amount of carbon and other alloying elements present, steel may be further divided into several varieties. Another significant iron alloy is cast iron, which has a greater carbon content than steel. Cast iron's distinctive brittleness is due to its increased carbon content, which also makes it more ideal for uses requiring strength and stiffness, such as engine blocks, pipelines, and large machinery. Excellent mechanical characteristics of iron and its alloys include strong tensile strength, good ductility, and heat conductivity. These qualities, together with iron's availability and affordable price, make it an essential commodity in contemporary culture. However, iron is prone to corrosion when exposed to oxygen and moisture, which causes the production of rust or iron oxide. Galvanizing, painting, and the use of corrosion-resistant alloys are just a few of the surface treatments and coatings used to prevent corrosion on iron. Iron is a versatile, widely utilized metal with superior mechanical qualities. Numerous industries have been transformed by its alloys, especially steel and cast iron. Iron and its alloys continue to be essential in defining the contemporary world, from building to transportation.

Pig Iron: Pig iron is a product used as an intermediary step in the manufacturing of iron and steel. Limestone, coke, and iron ore are smelted together to create it, usually in a blast furnace. Because it was historically cast into pig molds for storage and transportation, pig iron earned its name. Pig iron is produced via a number of steps. First, crushed iron ore that often takes the form of iron oxides like hematite or magnetite is combined with coke and limestone. Limestone functions as a flux to remove impurities, while coke operates as a source of carbon, which is required for the reduction of iron oxides. The combination of iron ore, coke, and limestone is subsequently put into a blast furnace, a tall, cylinder-shaped furnace with a refractory material coating. Intense heat is produced by blowing hot air into the furnace's bottom. Carbon monoxide, a reducing agent, is created when the coke and oxygen in the air react. Following a reaction between this carbon monoxide and the iron oxides, metallic iron is produced.

The bottom of the blast furnace is where the molten iron and slag, a byproduct of the operation, collect. The majority of the iron ore and flux components' impurities, including silica, alumina, and calcium oxide, make up the slag. Since it floats on top of the molten iron and is lighter than it, it is simple to separate. By tapping or draining the molten iron and slag via a hole towards the bottom of the blast furnace, pig iron may be removed. The term pig iron refers to the process of casting the molten iron into molds that are customarily fashioned like pigs. For simpler transportation and processing, these molds enable the pig iron to form into bars or ingots. In addition to additional impurities like silicon, manganese, sulfur, and phosphorus, pig iron has a high carbon content that normally ranges from 2% to 4%. Due to its high carbon concentration and impurities, it is brittle and has a restricted range of applications in its raw state. But pig iron is a vital component of the raw materials used to make steel. Impurities and the carbon content of pig iron must be decreased in order to turn it into steel. This is accomplished using a number of techniques, including the basic oxygen furnace (BOF) or the electric arc furnace (EAF), where pig iron is refined and alloyed with other components to make various grades of steel. In conclusion, pig iron is a byproduct used in the manufacture of iron and steel. It is produced by smelting iron ore in a blast furnace and contains impurities and a high carbon content. In order to produce steel, which needs to be further refined and alloyed to attain the appropriate qualities for a variety of industrial uses, pig iron serves as an essential raw material.

Cast Iron: A form of iron alloy known as cast iron has a greater carbon content than steel, often between 2% and 4%. It is distinguished by outstanding castability, strong wear resistance, exceptional machinability, and special qualities that fit a variety of applications. Cast iron is produced by melting iron in a furnace together with appropriate amounts of scrap iron, recycled cast iron, and alloying components. After being put into molds or castings, the liquid iron hardens and adopts the shape of the mold. Cast iron is made by a casting process that produces elaborate and complicated structures. Cast iron comes in a variety of forms, each having special qualities and uses. Gray iron, white iron, ductile iron, and malleable iron are the four primary varieties of cast iron. The most often used variety of cast iron is called gray iron. It has flakes of graphite microstructure, which gives it its distinctive gray hue. Excellent machinability is provided by the internal lubrication provided by the graphite flakes. The characteristics of gray iron include a low melting point, high heat conductivity, and damping capacity. Applications for it include mechanical components, pipelines, fittings, and engine blocks.

a. **Gray Iron:** Cementite (Fe_3C) is present in the microstructure of white iron, which is a hard and brittle kind of cast iron. It is utilized in applications requiring strong abrasion and impact resistance due of its high wear resistance, including grinding balls, crusher liners, and mining equipment.

b. **White Iron:** Nodular graphite microstructure, commonly known as ductile iron or spheroidal graphite iron, is what gives this material its name. When compared to gray iron, the nodules of graphite offer better toughness and ductility. Due to its high strength and impact resistance requirements, ductile iron may be used for gears, crankshafts, and automotive parts. It also has strong wear resistance and shock absorption qualities.

c. **Ductile Iron:** White cast iron or ductile iron are heat-treated to create malleable iron. The carbon in the microstructure is transformed into graphite clusters during this heat treatment process, creating a material with increased ductility and toughness. Because malleable iron is easily moulded, bent, and formed, it may be used to make hand tools, agricultural machinery, and pipe fittings.

d. **Malleable Iron:** Compared to other materials, cast iron has a number of benefits. Due to its high carbon content, which offers great hardness and wear resistance, it is suited for applications involving abrasive materials and high levels of stress. Cast iron is perfect for applications where heat distribution and retention are crucial, such as in cooking utensils and stoves, because it also has strong heat retention qualities.

Cast iron does have certain restrictions, though. Because of its lower tensile strength and greater brittleness than steel, it is more prone to fracture when under stress. Additionally, it is prone to corrosion, especially in humid and acidic settings. Cast iron is frequently coated or treated with protective coatings to strengthen its corrosion resistance in order to minimize these limitations. Cast iron, an adaptable iron alloy with a greater carbon content than steel, is concluded. Due to its special qualities, which include outstanding castability, wear resistance, machinability, and heat retention, it may be used in a variety of fields, including manufacturing, construction, agriculture, and the automotive industry. It is possible to choose the best material for certain purposes by being aware of the various cast iron varieties and their qualities.

Application of Ferrous Metals: Iron and its alloys, which make up the majority of ferrous metals, have a wide range of uses in several sectors. The distinctive qualities of ferrous metals, including their high strength, tensile strength, and magnetic properties, make them appropriate for a variety of uses. The following are some essential uses for ferrous metals:

a. **Construction:** The usage of ferrous metalsespecially steelin this sector is widespread. Beams, columns, and frames made of steel provide buildings, bridges, and infrastructure projects strength and stability. Steel reinforcing bars, sometimes known as rebar, are used to reinforce concrete constructions.

b. **Automotive and Transportation:** Ferrous metals are essential to the automotive and transportation sectors. Due to its strength, impact resistance, and formability, steel is employed in the construction of car bodywork, engine components, chassis, and suspension systems. Because of its durability and heat resistance, cast iron is used in engine blocks, cylinder heads, and brake components.

c. **Equipment and Machinery:** Ferrous metals are frequently used in the production of equipment and machinery. Gears, bearings, shafts, and other mechanical parts requiring great strength and wear resistance are made of steel. Cast iron's stability and vibration-dampening qualities allow it to be used in machine bases, frames, and heavy-duty equipment.

d. **Energy and Power Generation:** Ferrous metals play a critical role in the production of energy and electricity. Oil and gas pipelines, as well as those building power plants, require steel pipes. Due to their strength and magnetic qualities, ferrous metals, such as steel rotors and casings, are frequently used in the construction of turbines and generators in power production facilities.

e. **Household Appliances:** For structural integrity and longevity, many household appliances, including refrigerators, stoves, washing machines, and dishwashers, rely on ferrous metals. Due to its resistance to heat, corrosion, and impact, steel is frequently employed in the production of these appliances.

f. **Tools and Hardware:** Ferrous metals are widely employed in the manufacturing of tools and hardware. Due to their hardness, toughness, and wear resistance, steel alloys like high-speed steel and tool steel are used to make cutting tools, drills, saw blades, and wrenches.

g. **Packaging and Containers:** Ferrous metals, notably steel, are frequently used in the packaging sector for containers and packaging. For many items, including food, drinks, and aerosol cans, steel cans and containers offer durability and protection.

h. **Aerospace and defense:** Ferrous metals are used in both of these industries. Aerial structures, landing gears, engine parts, and missiles all employ steel and titanium alloys because of their durability, corrosion resistance, and high temperature stability.

i. **Electronics and Electrical Equipment:** Ferrous metals are used in the production of electrical and electronic equipment. Due to their outstanding magnetic characteristics, soft magnetic alloys like iron-nickel alloys (such as Permalloy) are utilized in the manufacture of transformers, inductors, and magnetic shielding.

j. **Recycling:** Ferrous metals are highly recyclable, making them a crucial component of the recycling sector. In order to create new metal goods, scrap ferrous metal is gathered, processed, and reused, which cuts down on waste and the demand for raw resources.

These are just a handful of the numerous uses for ferrous metals. They are widely used in many sectors and play a significant part in modern infrastructure, technology, and day-to-day living because to their vast availability, mechanical qualities, and adaptability.

III. CONCLUSION

Iron and carbon alloys play a significant part in modern civilization, finding use in a variety of sectors ranging from construction to the production of automobiles. Because of their remarkable mechanical qualities, such as great strength, endurance, and malleability, ferrous metals are used widely. Additionally, the affordability and quantity of iron resources add to the attraction of ferrous metals. The effects of the production, usage, and disposal of ferrous metals on the environment must be taken into account. Environment-degrading processes, such as habitat destruction and water contamination, can result from the mining of iron ores and subsequent processing. Additionally, rust can occur as a result of the corrosion of ferrous metals, degrading aesthetics and perhaps jeopardizing structural integrity. Through enhanced production methods, recycling programs, and the creation of substitute materials, efforts are being undertaken to alleviate these environmental issues. Recycling ferrous metals reduces trash production, energy use, and natural resource depletion. Research on corrosion-resistant coatings and alloys also attempts to prolong the useful life and sustainability of ferrous metal applications. In conclusion, ferrous metals remain crucial in several sectors because of their excellent qualities and affordability. However, it is necessary to weigh their advantages against environmental factors and work toward sustainable manufacturing, usage, and disposal methods. The long-term survival and environmental compatibility of ferrous metals will largely depend on future research and technical developments.

REFERENCES

[1] J. B. Huang, Y. M. Luo, and C. Feng, An overview of carbon dioxide emissions from China's ferrous metal industry: 1991-2030, Resour. Policy, 2019, doi: 10.1016/j.resourpol.2018.10.010.

[2] H. Chi, J. Wan, Y. Ma, Y. Wang, S. Ding, and X. Li, Ferrous metal-organic frameworks with stronger coordinatively unsaturated metal sites for persulfate activation to effectively degrade dibutyl phthalate in wastewater, J. Hazard. Mater., 2019, doi: 10.1016/j.jhazmat.2019.05.081.

[3] J. Liu et al., Immobilized Ferrous Ion and Glucose Oxidase on Graphdiyne and Its Application on One-Step Glucose Detection, ACS Appl. Mater. Interfaces, 2019, doi: 10.1021/acsami.8b03118.

[4] B. Chen et al., In search of key: Protecting human health and the ecosystem from water pollution in China, J. Clean. Prod., 2019, doi: 10.1016/j.jclepro.2019.04.228.

[5] J. Wang, J. F. D. Rodrigues, M. Hu, P. Behrens, and A. Tukker, The evolution of Chinese industrial CO2 emissions 2000–2050: A review and meta-analysis of historical drivers, projections and policy goals, Renewable and Sustainable Energy Reviews. 2019. doi: 10.1016/j.rser.2019.109433.

[6] X. Wu, K. Chen, Z. Lin, Y. Zhang, and H. Meng, Nitrogen doped graphitic carbon from biomass as non noble metal catalyst for oxygen reduction reaction, Mater. Today Energy, 2019, doi: 10.1016/j.mtener.2019.05.004.

[7] Y. Zhou, R. C. Tang, T. Xing, J. P. Guan, Z. H. Shen, and A. D. Zhai, Flavonoids-metal salts combination: A facile and efficient route for enhancing the flame retardancy of silk, Ind. Crops Prod., 2019, doi: 10.1016/j.indcrop.2019.01.020.

[8] A. Y. Tamakhina and A. A. Akhkubekova, Monitoring of structure of plant communities on waste dumps from non-ferrous metals enrichment, Theor. Appl. Ecol., 2019, doi: 10.25750/1995-4301-2019-2-061-067.

[9] H. E. Kim et al., Differential Microbicidal Effects of Bimetallic Iron-Copper Nanoparticles on Escherichia coli and MS2 Coliphage, Environ. Sci. Technol., 2019, doi: 10.1021/acs.est.8b06077.

[10] M. Guo et al., Fingerprinting Electronic Structure of Heme Iron by Ab Initio Modeling of Metal L-Edge X-ray Absorption Spectra, J. Chem. Theory Comput., 2019, doi: 10.1021/acs.jctc.8b00658.