Fabrication Methods, Recent Developments and Applications of Carbon-Carbon Composites (CCC): A Review

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Abstract - *Carbon Fibre Reinforced Carbon (CFRC) or Carbon-Carbon(C-C) or Carbon-Carbon Composites (CCC) is an exceptional composite material comprising of carbon filaments implanted in a carbonaceous framework. Initially produced for aviation applications its low thickness, high warm conductivity and brilliant mechanical properties at hoisted temperatures make it a perfect material for flying machine brakes, rocket spouts and reentry nose tips apart from a few modern and biomedical applications. The carbon-carbon item innovation is adaptable and offers outline adaptability. It withstands temperatures more than 2000°C without significant deformation.*

This paper audits significant advancements of Carbon-Carbon(C-C) composites and portrays about manufacturing process innovation. This paper likewise tells about the exploration and utilization of carbon-carbon. Enhancing properties by different procedures and reducing the manufacturing costs make this group of materials more appealing for designing applications, especially high temperature applications.

Key Words: Carbon-Carbon Composites (CCC), Fabrication, Properties, Developments, Applications.

1. INTRODUCTION

Composite substances are made of a blend of two or greater materials with a unique mechanical, chemical or bodily properties. Like all other composite substances, CCC integrate major factors like carbon fibres and the carbon matrix. The houses of CCC are substantially progressed and extra appropriate for plenty of applications [1]. CCC is desired over different substances because they hold stability and carry out structurally at maximum temperature due to mild weight, strong stiffness, durability, superior thermal coefficients and excessive speed friction resistances. The additives of CCC had been manufactured in the US in last three decades for maximum aerospace and defense programs. CCC combine splendid mechanical property to weight ratios and splendid refractory properties making them the substances of preference for excessive and difficult environmental programs including atmospheric reentry, strong rocket motor exhaust and disk brakes in high-performance navy, business aircraft, speed trains and racing cars [2,3].

1.1 Components of CCC

CCC are notable for their astounding properties. These properties rely upon a chosen set of parts and how they are orchestrated and facilitated. The matrix segment and the fibre segment two noteworthy components of a CCC structure. These components can be in various structures, for instance, fibres can be in the type of single strands, plentiful strands or plaited. The bearing and the layering of the picked fibre is the controlling capacity in deciding the attributes of the accomplished composite casing. The matrix framework plays a noteworthy role within the composite structure. Network framework is in charge of holding the strands in their required area and exchanging the heap also, worry between the strands. It additionally goes about as an obstruction from the antagonistic condition and secures the filaments from the mechanically scraped spot. The matrix likewise gives noteworthy upgrade in numerous mechanical properties making the composite structure extremely solid contrasted with a solitary traditional material [4, 5].

CCC is driving the majority of the composite materials in protecting the mechanical properties, for example, durability and high quality at high temperatures more than 3000°C. Jewel, graphite, fullerenes are the three allotropic types of the carbon utilized in CCC. Any kind of these carbon frames has its own particular critical use in producing and modern fields. Graphite can be accessible in substantial amounts and in various shapes with an evaluated thickness of 2.2 g/m^3. Carbon materials have a high particular quality of right around 50 GPa and keep up this high quality at raised temperatures of more than 1500°C [6].

CCC can retain warm without misshaping on account of its low coefficient of the warm extension in the fibre heading (0.3-0.5mm) and (0.5-0.8mm) in the opposite course and wear rates (0.05-0.1mm) and (0.1-0.3mm) in the fibre bearing an opposite course individually [7, 8].

2. FABRICATION METHODS

2.1 Conventional Fabrication Processes

In Fibre orientation and the portion of the fibre in the required course controls the houses of the CCC fabricated. Fibre shape explains the development of preforms in easy blocks, cylinders, cones, contours, surfaces of revolution and complicated geometries and shapes. To fill the interstices between the fibres there are two routes:

- Gas phase route using the chemical vapour deposition process.
- Liquid route using thermosetting pitch or resin.

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Gas Phase Route-Chemical Vapour Deposition (CVD*)*

In CVD, risky hydrocarbons like methane, propane, benzene and different low molecular weight devices are used as precursors. A warm decay of the hydrocarbons takes region at the heated floor of carbon fibres and deposition of carbon takes area. This approach of depositing carbon on to dry fibre carry out pyrolytically is known as chemical vapour infiltration/deposition [1].

Liquid Route Impregnation Process

Here impregnation is finished with fluid impregnates like coal tar or oil pitches and high burn yielding thermosetting gums. CCC manufacture may include different impregnation for apparent thickness, trailed by hot isostatic squeezing at temperatures 750°C and 100 MPa weight. This is trailed via carbonization at 1000°C and graphitization at 2750°C. Reactivity of carbon towards oxygen past 500°C is of genuine concern thus a fair oxidation obstruction is to be gotten. Strategies like surface coatings utilizing CVD, pack cementation and so forth. SiC coatings and sol-gel techniques, impregnation with inorganic salts, a fuse of oxidation inhibitors and so on are some [1].

Tongshik Chang et al.[10] created CCC by basic hot squeezing (600°C and 49 MPa) of pummeled coke powders (3.5μm) as grid, carbonaceous mass mesophase (BM) as fastener and carbon filaments as fortifications as sheets impregnated with epoxy pitch in unidirectional(UD) long strands (UD1 more slender, UD2 thicker) and cloth(CL) frames (CL1 more slender, CL2 thicker). From the delayed consequences of the water substitution technique and 3 point bowing tests, most extreme thickness and quality were acquired at ideal hot squeezing weight i.e. 49 MPa at 600°C. The greatest quality estimations of 119 MPa and 130 MPa were acquired for UD1 (V_f = 30%) and UD2 (V_f = 46.4%) at BM proportion 70% and 80% individually in a grid. At the point when CL1 and CL2 were utilized quality was observed to be lower than that of UD at V_f = 20%.

2.2 Changes in Conventional Fabrication Methods

A couple of adjustments to the traditional fluid stage impregnation can be recorded as discussed below:

- Before fluid impregnation, filaments are pre-impregnated with tar or pitch and carbonized at 350-800°C under a weight of 100 MPa. Fluid stage impregnation (LPI) in a vacuum includes more pitch and gum, which will build the thickness and between laminar shear quality. Graphitization at 2200-3000°C opens up the shut pores and a further impregnation will prompt higher thickness.
- Hot isostatic weight impregnation carbonization (HIPIC) is yet another improvement around there in which a high weight of 100 MPa is connected while carbonization and impregnation at 650-1000°C. This builds the carbon yield and keeps up more unstable parts of contributing a dense stage. It is then graphitized at temperatures more than 2000°C without weight. This yields CCC with higher thickness.
- Hot pressing is another progress where carbonization at 650-1000°C and 76 Mpa out of a dormant decreasing or vacuum environment is trailed by graphitization at 2200-3000°C without weight.

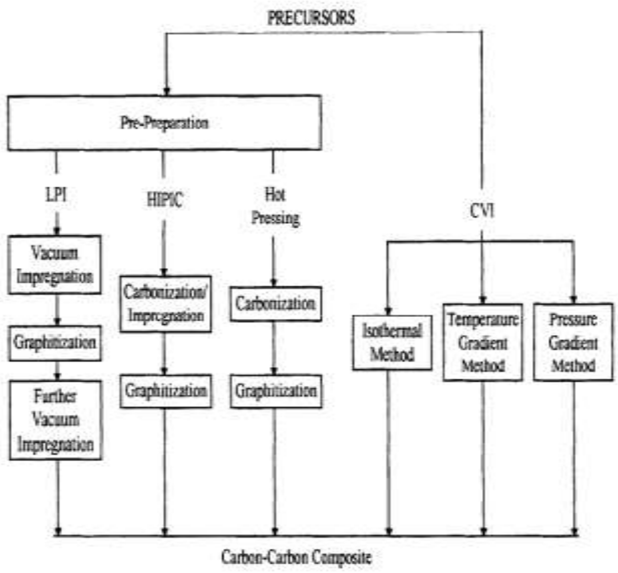

Fig -1: Modifications in conventional fabrication methods

2.3 Advanced Fabrication Methods

Preformed Yarn (PY) Method

Dissimilar to the ordinary assembling strategies like impregnation and CVD, a Preformed Yarn (PY) of 3 to 4mm width and 200 to 1000 mm long was set by N. Hirotaka et al. [11] in the PY strategy. PY has PAN-based carbon fiber as the support, coke powder and oil mesophase pitch (cover) as grid antecedent and polypropylene globules as the polymer that coats the carbon fiber and framework forerunner. At that point, a PY square was made by unidirectionally adjusting PY sheets which were set up by the heaping up of slashed PYs. Hot squeezing of the PY hinder in a metal shape was completed at 600°C (10°C/min) which was then subjected to carbonization at 800°C and graphitization at 2000°C to get the last CCC.

- 3 point twisting tests demonstrated enhanced flexural quality and modulus than that gotten by regular techniques by a factor of 1.3.
- Small-scale basic investigations uncover good fiber/lattice holding a minimal number of pores were perceived.

P. Naik et al. [12] altered the technique and utilized carbon fiber (PAN based) as support and pitch, coke and nylon-6 as lattice materials in PY strategy to manufacture CCC for aviation brake cushion application.

The PY arranged here was a fiber package encompassed by coke and contribute which was encased Nylon-6. Three sorts of tests having a fiber weight rate of 30%, 40% and 50% were created. This was trailed by hot squeezing at 600°C and warm treatment at 1800°C. To dispense with porosity and to accomplish the required thickness one cycle of pitch impregnation was done on the examples by hot isostatic squeezing.

From the hardness test, pressure test, affect the test and crack strength test enhanced mechanical properties were gotten when carbon fiber volume % was expanded. The thickness of the acquired composite enhanced from 1.55g/cc to 1.60g/cc while the carbon fiber expanded from 30 to 40% which again demonstrated a change to 1.65g/cc when carbon fiber was half. The comparative pattern was seen in the instances of hardness, compressive quality, flexural quality, affect the quality and flexural modulus

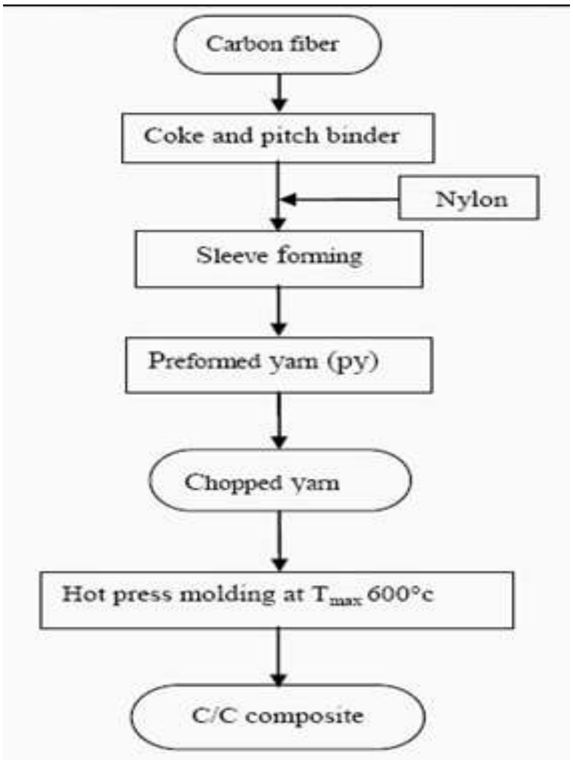

Fig -2: PY method

CCC For Nuclear Reactors

Venugopal.R et al. [13] created CCC by impregnation technique in which performs made utilizing PAN carbon strands were stacked to 2D preform utilizing phenol formaldehyde tar. Rectangular green performs were sliced and carbonized at 1000°C to get a very permeable example which was then densified utilizing two cycles of impregnation of fluid formaldehyde pitch under strain in steps.

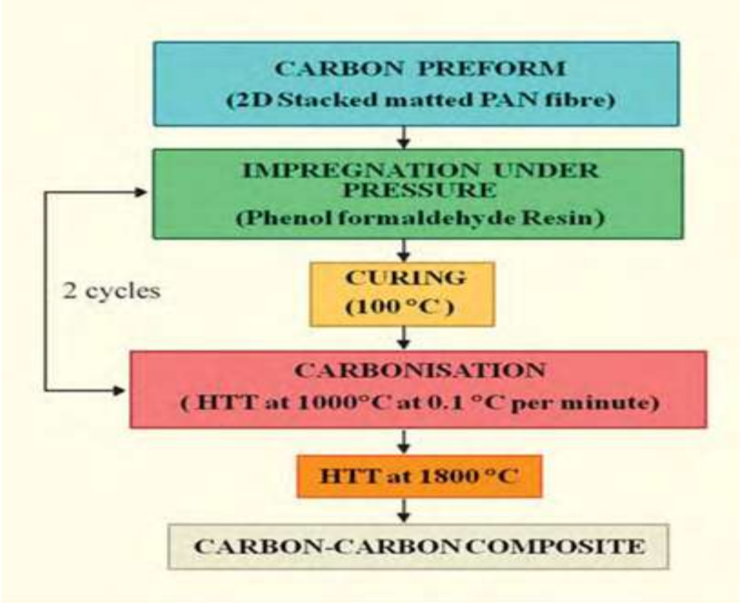

Fig -3:CCC fabrication for nuclear reactors

The accompanying ends were drawn:

- CCC with a thickness of 1470 kg/m³ was obtained.
- XRD uncovered that the composite was shapeless in nature.
- Higher the impregnation weight bring down the porosity.
- X-beam tomography indicated diminish in splits and better framework pitch holding at higher weights.
- SiC covering by CVD technique was improved the situation oxidation obstruction, warm stun properties and solidness against hot consumption making it appropriate for low-temperature reactors.

3. RECENT DEVELOPMENTS TO ENHANCE MECHANICAL PROPERTIES FABRICATED BY DIFFERENT TECHNIQUES

3.1 Application of Temperature

Various elements which have an effect on mechanical houses of CCC at increased temperatures (2273K) are:

- High-temperature houses of fibre, matrix and the fibre-matrix interface
- Effect of an evolution of absorbed gases
- Creep deformation
- Thermal pressure

After suitable tensile checks and creep, assessments on the 2D laminate CCC specimens at elevated temperatures, Goto.K et al. [14] concluded that the tensile strength of CCC improved with a utility of temperature. This can be because of the above-noted factors wherein predominantly as much as a temperature of 1773K the evolution of absorbed gases (degas phenomenon) have contributed to power development of matrix and for temperatures above 1773K it is creep deformation. The strain-strain curves have been determined to be non-linear above 1873K as an awful lot as 2273K.

3.2 Densification

The densification of cross handle overlay CCC created by 3 preparing courses in particular preformed yarn (PY), resin char (RC) and hot isotropic press (HIP) was completed by H. Hiroshi et al.[15]. An expansion in thickness of CCC from 1.6g/cm^3 to 1.95g/cm^3 was acquired. PY CCC was densified by rehashing tar scorch cycles, contribute penetration at 60^{o}C in 10 MPa Argon, carbonization at 600^{o}C out of 10 MPa air and graphitization at 2000^{o}C in a vacuum. Sap singed CCC were densified via carbonization at 600^{0}C and graphitization at 2000^{o}C. Tar scorched CCC, strengthened by IM-600 and UM46 strands were meant by RCI and RCU. Hot isotropically squeezed CCC was densified by rehashed cycles and was indicated by HIP1 to 5 in which the number stands for rehashed cycles.

Tensile test, interlaminar shear test and in-plane shear tests were done on the previously mentioned CCC.

The accompanying were the outcomes:

- Tensile test: RCI and RCU displayed increment in rigidity while HIPs demonstrated a diminishing pattern.
- Stress-strain relation: Densified PYs demonstrated a change in Young's modulus; a slight change in quality, while for HIPs quality decreased when densified because of corruption of crack strain.
- Interlaminar shear quality: Densified PYs and HIP5 display high estimations of shear quality surpassing 10 MPa while RCI, RCU and HIP1, 2, and 3 indicated low estimations of shear quality.
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All the above outcomes indicate out the way that a low interfacial quality amongst fiber and grid prompt a huge change in the rigidity of CCCs.

3.3 Increasing the Number of Pitch/Resin Impregnation Cycles

Jan Cheopek et al. [16] created CCC plates by prepeg technique, where a preform was got from phenol formaldehyde pitch and carbon strands in the wake of squeezing, relieving and carbonization. This was trailed by pitch impregnation of the preform (chemical vapor impregnation) at 215^{o}C, 10 MPa, carbonization at 1000^{o}C and graphitization at 2500^{o}C.

The mechanical properties of CCC enhanced with increment in the quantity of pitch/sap impregnation cycles and additionally with an increment in the degree of graphitization. High-temperature warm treatment guarantees a more arranged graphite structure with enhanced thickness and quality. The versatility of CCC is vital to the extent biomedical applications are concerned. The kind of filaments, introduction and porosity of strands oversee this.

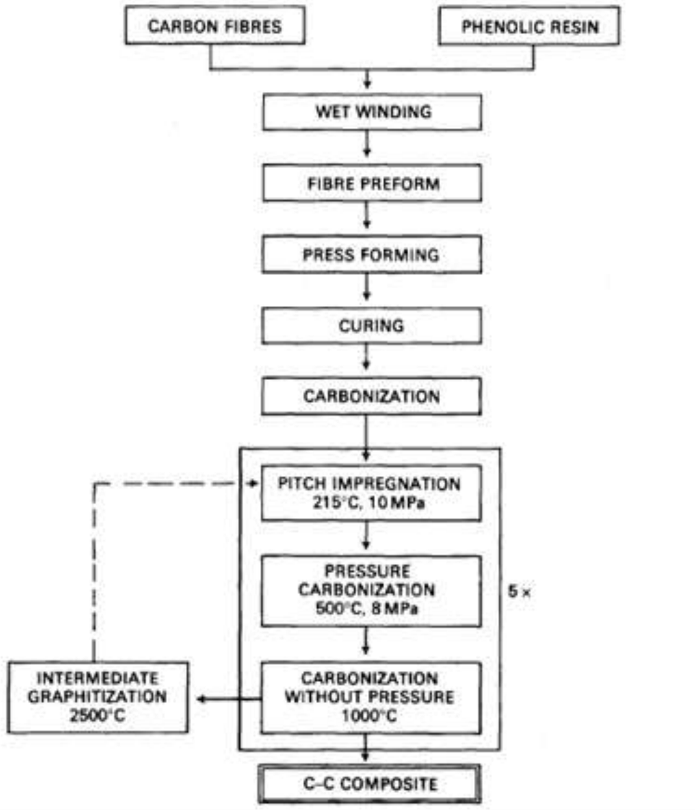

Fig -4: Prepeg Method

3.4 Carbon Nano Tubes and Carbon Nano Fibres as Reinforcements

Due to their prevalent mechanical properties, carbon nanotubes (CNT) and carbon nano strands (CNF) were picked as composite fortifications by T.Shyong et al. [17] Ultrasonification to blend CNT and phenolic tar was trailed by a vacuum pack hot squeezing strategy to create phenolic tar composite. This was trailed by warm medicines (carbonization at 1000^{o}C in Ar environment and after that at 1400^{o}C in He climate) to change over into CCC.

3 point bending test was utilized to ponder the mechanical properties and crack conduct. Contemplating the change in flexural quality, CNF turned out to be preferred fortifications over CNT because of better interfacial holding with a superior outcome for modulus estimation moreover. For CCC, CNT support (carbonized at 1000^{o}C and 1400^{o}C) demonstrated to indicate preferred outcomes over CNF strengthened. Anyway, CCC warmth treated at 2400^{o}C demonstrated great flexural quality qualities.

3.5 Carbon Fibre Felt and PAN Carbon Fibre Felt Reinforcements

With an expected to enhance the mechanical quality, crack durability and warm pressure safe properties, Kurumada.A et al. [18] created two composites CCA (47 wt% carbon felt) and CCB (34 wt% carbon felt). These were acquired by strengthening and binding, pitch carbon felt and PAN carbon felt with coal tar pitch. Rigidity, break strength, Young's modulus and warm stun obstruction were tentatively decided at 2400^{o}C by reasonable tests. These properties were contrasted and as of now arranged plate composites CCC by heaping 12 layers of rayon carbon fiber materials and an isostatically shaped fine grain oil coke graphite IG-11. As revealed Tensile quality CCB has 20% higher than CCA twice when contrasted with that of IG-11.

4. APPLICATIONS AND IMPORTANCE

Many of the CCC currently being produced are inside the shape of additives for missiles and military plane. The maximum critical packages encompass reentry bodies, rocket nozzles and exit cones for strategic missiles and brake discs for a navy plane. Recently a commercial aerospace application in which brake discs for shipping aircraft was covered has grown to be prominent. The use of CCC brake discs on business transport aircraft has to turn out to be a considerable business and is expected to grow in the coming years.

Specific advanced army packages consist of hot segment components for restrained-lifestyles missile engines, exhaust elements for brand new fighter aircraft, hypersonic vehicle fuselage and wing additives and systems for area protection satellites. There are many advantages of using CCC as braking materials such as lightweight applications, inertness with other materials and high thermo mechanical performance. CCC has a capacity to ingest much vitality in a brief timeframe compared with other materials such as a metal or organic brakes. Aircraft, trains and racing cars preferring CCC are a metal alternative because CCC reduce friction by using materials that perform at a lower weight. Also, the low density of CCC coupled with a tendency towards lower cost makes it ideal for applications in transport or machinery.

Expanded use of CCC in industries aside from protection and aerospace will likely require the improvement of methods that reduce value but keep homes that offer performance blessings. Potential near-term makes use of that have been recognized are high-velocity and special car brakes, clutches, forging dies, molding crucibles, corrosive chemical reactors, warmth exchangers, fuel cells, high thermal conductivity electronic substrates, prosthetic devices and additives for inner combustion engines. More distant massive-scale programs consist of plasma limiters for nuclear fusion gadgets and inert gasoline ducting and heat exchangers for gas-cooled fission reactors.

Fig -5: Airplane brake disk

Fig -6: F-14 Tomcat-one of the first aircraft to use carbon composites

Fig -7: Formula1 brake disk made of carbon -carbon composites

5. CONCLUSIONS

In this paper, a comprehensive review on CCC is presented addressing the fabrication techniques, advancements in fabrication techniques, properties and applications.

CCC is an extraordinary institution of composite materials that continues to use its houses to the maximum temperatures, lightest weights, inertness and excessive degree of longevity compared with other materials. These properties make CCC perfect for the most advanced programs in the mechanical engineering fields. The risks that restrict the distribution and development of CCC are fabrication processes used and oxidation is speedy in surroundings at a temperature over 400^{o} C.

CCC used within the business sectors as brakes, warmness exchangers and furnace elements are constrained by means of price unlike in military fields as rocket components, jet engine parts and brakes. CCC will stay the very best overall performance substances through the coming years.

The future of CCC is very obvious in any one of a kind industries particularly in windmills, compressed herbal gasoline storage, transportation and gasoline cells. Also, CCC has a vivid future in gasoline green cars. It extends to apply in a very excessive call for on creation and infrastructure. For instance in the era of earthquake safety and mild weight pre-cast concrete. CCC has a first-rate destiny in the oil industry, especially in kill strains, drill pipes and deep sea drilling platforms.

High costs in the fabrication processes have restricted the abundant use of CCC and of this reason, there is always a greater opportunity for researchers to develop new fabrication techniques which will effectively reduce the cost of fabrication without compromising the extra brilliant properties of this class of composites.

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