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Recent Advances in durability of superhydrophobic self-cleaning technology: A critical review

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ABSTRACT

Self-cleaning concept has achieved significant attention because of their distinct features and inclusive range of probable applications in various fields. Inspired from the lotus effect; the self-cleaning properties showed by the leaves due to the micro and nanoscopic design which reduces the water droplets adhesion to the surface, self-cleaning technology (SCT) plays a significant role in the current time in various applications. One of its special features is its ability to keep the surface clean and maintain the self-cleaning property stable under severe environmental conditions over an intended period of time. This review introduces an overview of the fabrication techniques for superhydrophobic coating and self-cleaning (SC) applications in various fields. The SCT has applications in areas such as textiles, cotton-fabrics garments, buildings construction, lavatories, domestic-automobiles windows, architectural heritage, and photovoltaic and solar cells. As SCT has wide range of applications, there is a need for a deeper understanding of the resilience and preparation of SC surfaces. Therefore, we have discussed the major applications of SCT in building, toilet, mineral paints for architectural heritage, photovoltaic devices or solar cell, fabrics or textile industry in this review. Apart from this, we have also added information regarding the techniques of SC superhydrophobic surfaces and flexible self-cleaning materials and their applications. SCT naturally suffers from great issues in their durability and stability. As the durability of SCT is significant in daily human life, it is intensively reflected in this literature survey. Furthermore, the ongoing progress and potential efforts in the recent innovative applications of SCT along with the critical conclusions, forthcoming views, and obstacles on the field of the durability of SCT are discussed in the presented survey.

1. Introduction

Self-cleaning is one of the most discussed topic at present due to their ability to clean the surface without any external source [1–9]. The inspiration from the lotus leaf effect due to the micro and nano-hierarchical surface morphology and low surface energy material covered on the surface repels the water droplets on the surface [1–4]. Several review articles were focused deeply on this subject and also continuous research works carried out by the inspiration of lotus leaf self-cleaning property and developed various novel materials for continuous improvement of this field for diverse applications. The most basic principle of self-cleaning (SC) technology is the properties of forming a spherical water droplet that can remove dirt particles on the surface. The essential conditions for producing self-cleaning are the mixture of surface hydrophobic epicuticular wax, and a hierarchical structure. This can contribute to obtain high and low values of water contact angle (CA) and sliding angle (SA), respectively [10]. On the other hand, the use of photocatalytic materials with hydrophilic or super hydrophilic surfaces can also add to its excellent self-cleaning property due to easier degradation or decomposition of the organic contaminants through the

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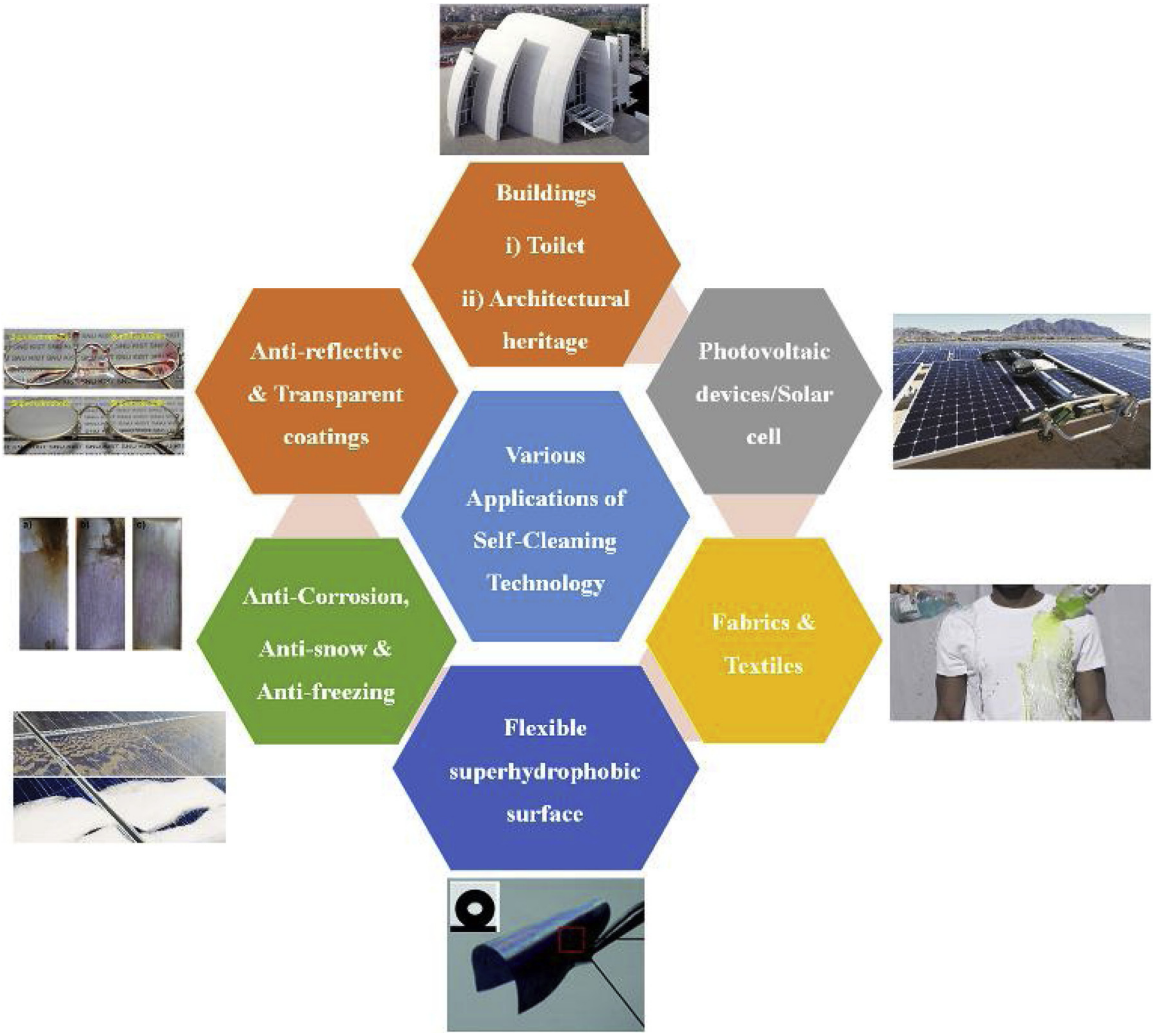

Fig. 1. Self-cleaning technology in various kinds of applications.

photocatalytic activity of the materials [9]. Nanotechnology is playing an important role of developing self-cleaning surfaces because of the use of nanoparticles alone can disperse well on various substrates more uniformly and generate hierarchical morphology [11–13]. The adhesion of mono disperses or aggregates of nanoparticles with photocatalytic property can show better self-cleaning property. Likewise, the combination of micro-nano particles with low surface energy materials can enhance the surface roughness and water repellence behavior which lead to perform the self-cleaning nature on the surface.

The inspiration from nature gives an idea to produce a non-complicated and cost-efficient method to create and fabricate self-cleaning surfaces that is superhydrophobic and will be used in advanced applications. We also provided the use of self-cleaning technology (SCT) for various applications as shown in Fig. 1. A review article written by Ganesh et al. [14] on SC coatings focused the use of hydrophilic and hydrophobic surfaces for self-cleaning coating and their various fabrication techniques and working mechanism. Xu et al. [15], reported on SC with and without water on the biomimetic SC surfaces.

Fig. 2 illustrate the continuous growth of self-cleaning technology from the number of papers published and number of times cited for the last 10 years. The figure also suggests the importance of this technology for the industrial applications. SCT is commonly used for daily applications in recent years. Self-cleaning surfaces are prepared by using hydrophilic photocatalytic materials or hydrophobic surface finishing agents [1–6]. In this review article, we mainly focused on the hydrophobically treated surface and their robustness. Self-cleaning surfaces were tested under harsh conditions such as temperature, pressure, humidity, and chemical corrosion. The major difficulties faced by SCT is the ability to withstand the surface property under harsh environmental conditions and also maintain the stability for prolonged time. Hence, research was done to overcome the drawbacks of SCT by enhancing the durability and stability of the coating under severe environmental conditions by the introduction of novel materials and methodologies. Designing and construction of durable and chemically stable superhydrophobic surfaces have become progressively meaningful and practical [16].

Durability enhancement of superhydrophobic surfaces is important for SCT it is necessary to develop a good superhydrophobic coating by using various methods such as hold limited abrasion resistance, corrosion free, efficiency, non-hazardous chemicals, and stability. Researchers endorse the use of environmentally friendly chemical agents such as fluorine-free organic chemical agents, which are not toxic for humans and environmental [17]. Recently, there have been several studies that enunciated the mechanical integrity of the superhydrophobic films, and assessed its outdoor robustness and abrasion resistance. The abrasion resistance was determined by measuring the change in a static contact angle, CA, hysteresis, and the coefficient of surface roughness [18].

Seeking for low-cost materials and developing one-step method has gradually become important in fabricating SC superhydrophobic surfaces. For this reason, Sas et al. [19] published a brief overview reporting on the idea of SC superhydrophobic surfaces and the

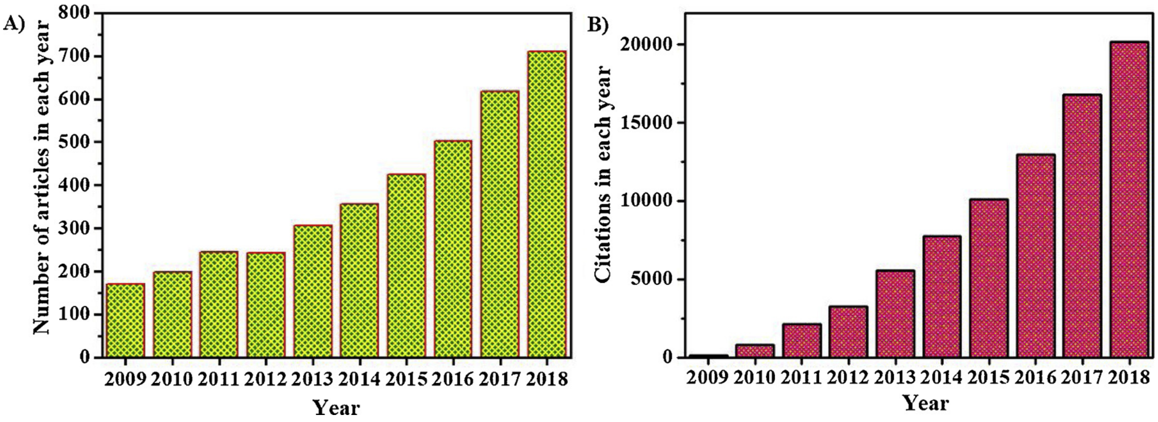

Fig. 2. Numbers of papers published (A) and numbers of times cited (B) from 2009 to 2018 under the topics of self-cleaning (Source: Web of Science).

fundamental concepts of the electrospinning procedure, therefore revealing the findings of several groups and their results on superhydrophobic behaviors. An alternative approach is necessary to make the preparation of SC surfaces cost-effective as well as environment-friendly. That will probably reduce time, energy, and the laundry cost [20]. The SCT have also applications in medical, textiles, athletic wear, outdoor fabrics, and military uniform that are often used in daily life. SCT fabrics are beneficial to human life as it effectively conserves water [21]. Much of SCT has been already been reflected in our daily life in different uses, such as in clothes, shoes, waterproof umbrellas and paints. When consumers buy a high-quality SC superhydrophobic product, it should have a good quality of glass of high efficiency, high durability, high stability and should be cost-effective. Therefore, the SC material efficiency and durability are two most important parameters to be considered at the time of fabrication. Many obstacles faced by SCT were recently resolved due to the extensive efforts that were made to enhance the SC- superhydrophobic films. As a result of the development in the field of fabrication and characterization of materials at the nanoscale, it became possible to design novel materials with special function parameters. This resulted in strengthening of the building materials making it more flexible with greater electrical resistance.

Researchers mainly focused on studying the properties of SC superhydrophobic including durability and efficiency in detail [22–25]. Previously, scientists conducted research in the field of synthesis, formulation, and testing different types of SC materials and surfaces, and had developed several technologies that were helpful to the industry. Recently, SCT has been studied with a different advanced application for fields like medical, architecture, biology, and environmental engineering [26]. The main objective of this review is to overview the significance of SCT durability. The most relevant research studies of the durability of SCT results were achieved in the last decade. The review discusses the various routes of fabrication of self-cleaning surfaces and their applications in various fields. In addition, we also discussed the importance of the fabrication of flexible SCT substrate and their use in different applications. Besides, we delivered some general conclusions of the most suitable fabrication methods and their applications for studying the durability, and recommend some future scenarios on how to develop them.

1.1. Advances of durability in SCT

In a 21st century, there is a major significance characteristic necessity for the durability of materials [27], which involves the conservation of SC behavior during their service period, proposed at 1–2 years. The durability of SCT can be governed by the appropriate requirements of high-temperature stability for a SC- superhydrophobic surface. Apart from this, parameters such as mechanical stability, resistance to corrosion, lightweight and chemical consistency are also few vital application requirements [28]. The main application of the superhydrophobic surfaces is to grow corrosion resistant films that can sustain harsh environments [29]. New synthesis techniques and surface modification methods that provide excellent adhesion and strength for the coatings on the substrates were reported [30]. It is worth mentioning that SCT is powerfully dependent on the availability and the cost of manufacturing techniques. SC materials such as Titanium Oxide (TiO_2) and zinc Oxide (ZnO) should be first identified, using a fabrication method, and should be tested for SC superhydrophobicity. The efficiency, stability, and durability of the optimized self-cleaning surfaces are thoroughly checked. Therefore, the optimal efficiency and durability of SCT are defined throughout this review paper.

Several researchers who are interested in SC coatings reviewed the work done in SCT [14,18–21,31–33]. Sakhuja et al. [34] thoroughly examined the planar and nanostructure glass samples for the SC properties, and their durability check was considered over an open-air exposure period of three months; their experiment depicted the SC and anti-reflective performance. Singh et al. [35] established a super-repellent surface using zirconium dioxide particles of water-soluble siloxane emulsion on cotton fabric. They also reported that the stability of a coated cotton fabrics (CCF) was detected by the extents of water CA after the usage of CCF with numerous tests such as ultraviolet irradiation stability, chemical stability, sandpaper abrasion test, and adhesion tape tear test with recurrences that are presented in Fig. 3**A**. The stability of the coating on cotton fabrics to withstand harsh external forces (such as pressure, temperature and bonding) was measured by the recurrent tear test of an adhesive tape. In their study, the cotton surface was fixed onto an adhesive tape, and then it was stripped off as presented in Fig. 3**B**. The synthesized material continued to be extremely resistant against all four tested solutions even after the recurrence of the tear test with the adhesion test for twenty repeated cycles with CA > 150°. Hence, the results of the study concluded that CCF has excellent stability of the covering on cotton fabric [35]. Quiroga et al. tested the lasting working conditions and performance of a commercially available SC coating of water-based titanium dioxide solution that was coated on three building materials that had played a significant role in the present and ancient European heritage such as concrete, Portland-limestone, and Woodkirk sandstone [36].

The assessment of durability was calculated throughout a year of outdoor exposure. The trail accelerated aging test was performed in the cavity with UV irradiation and condensation cycles. The results were compared with the outcome obtained by Munafò et al. [38] and Diamanti et al. [39]. The comparison of the durability studies showed minimal color variations, but even lower for the treated samples when compared with the untreated ones. Finally, it was concluded that the photocatalytic action remained unaffected by concrete and sandstone, and ordinarily after artificial ageing. Also, the photocatalytic action was lowered due to the elimination of nanoparticles from the facial layer.

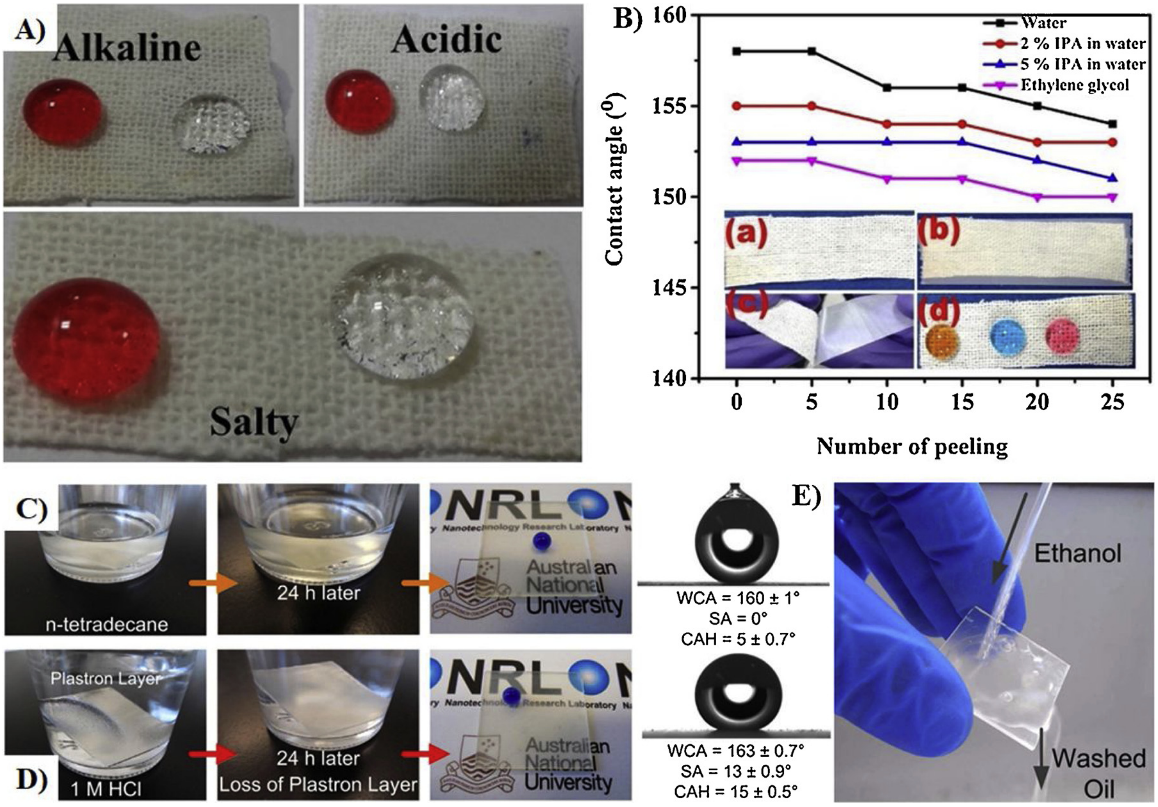

Fig. 3. **A)** Microscopic images of water (in red) and 1,2-Ethanediol (uncolored) droplets on coated cotton fabrics surface afterward 24 h of dipping in acidic, salty and alkaline aqueous solution (these images are reproduced from ref. [35], copyright 2014, Elsevier). **B)** Water CA on superhydrophobic cloth subsequent to recurrent tear test. The side image shows the tearing procedure (a) a cloth, (b) the piece of cloth was held onto a sticky tape, (c) the piece of cloth stripped off the sticky tape, (d) H_2O droplet on the piece of cloth subsequent to stripping off the sticky tape (these images are reproduced from ref. [35], copyright 2014, Elsevier). **C)** Dipping of Fluorine-silicon dioxide incorporated PU − PMMA IPNs into (c) oil and **(D)** acid for a period 24 h, along with the following loss of plastron films in both, showing outstanding a quick recovery from damaging and quickly recuperated functionalities (these images are reproduced from ref. [37] copyright 2016, ACS), **E)** Ethanol decontamination of oil-immersed superhydrophobic glass slides is reproduced from ref. [37], copyright 2016, ACS. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Whereas, for limestone, a reduction of Titanium dioxide concentration was noted, however, the photodegradation efficacy remained unchanged. Wong et al. [37] introduced a cost-efficient and mass-produced ultra-durable superhydrophobic films by fast template free micro-nano texture of integrated polymer structures. UV photodegradation tests were performed for a period of 50 h deprived of any significant variations in SAs and wet CAs as presented in Fig. 3**C**. A study involving 24 h of extended immersions of the PU − PMMA − F-SiO_2 interface into an oil analog and concentrated acid reported that there was no significant effect on the superhydrophobicity of the fascial layers (Fig. 3D). The contaminants from the oil were effectively removed with a flow of ethanol subsequent to the recovery as presented in Fig. 3**E**.

Varshney et al. studied the regenerated and durable superhydrophobic coatings with outstanding SC and anti-fogging behavior for aluminum surfaces [40]. The study concluded that these types of coatings exhibited excellent chemical, mechanical, UV and thermal stability and also this method can be used with various size and shape of the aluminum surface. Moreover, this method has many other industry-related applications. The diverse phases of the sticky tape stripping off test are demonstrated in Fig. 4**A (a–b)**. Subsequent to every stripping off cycle, superhydrophobicity was evidenced. It was also noted that the coating remain unchanged as the water droplets moved downwards, leaving the surface and this was repeated for 60 times of stripping as demonstrated in Fig. 4**A (c–e)**. During the 60 cycles, the coating lost its superhydrophobicity and became adhesive. The water droplets did not leave the surface, even though when the surface was sloped at 90° **(**Fig. 4**A (f))**. The several adhering and stripping-off the tape caused damage to the coated surface. Static CA showed minor changes in angle from 172° to 157° after single annealing at 250 °C, while the SA was not affected significantly. The UV stability of the superhydrophobic aluminum surfaces was examined by irradiating the sample with UV for many hours.

In the durability investigation, the effect of bending on SC superhydrophobic surfaces was a crucial property [41]. Latthe et al. studied the bending behavior of the superhydrophobic steel surface where the steel was curved to an angle ≥90°. The wetting condition of the curved surface is demonstrated in Fig.4**B (a–d)** [42]. Fig. 4B demonstrates the diverse views of the H_2O drop on the curved superhydrophobic steel surface. In the two cases, the curved surface displayed no variation in the superhydrophobic wetting condition and no sticking of the H_2O drops on the curved surface was noted. The superhydrophobic steel showed steady wetting quality under severe mechanical curving. The wettability changed to sticky superhydrophobicity after the sandpaper scrape test and the sticky tape stripping test.

The effect of the liquid–dipping time on the surface morphology and CA is presented in Fig. 4**C**. Fig. 4**C (a)** demonstrates a sporadic flake structure of 5 min on the surface. The surface was then covered with countless flake structures after 15 min as demonstrated in Fig. 4**C (b)**. After 30 min, the surface was homogeneously covered with the flake structures as demonstrated in Fig. 4**C (c)**. Further, after 40 min, the surface was still homogeneously covered with flake structures, but the sizes of the flake got enlarged (Fig. 4**C (d))**. The SEM images showed that the flake structures were created progressively as the liquid-dipping time was extending [43]. The SC and anti-fogging superhydrophobic coating on aluminum surface were manufactured by the

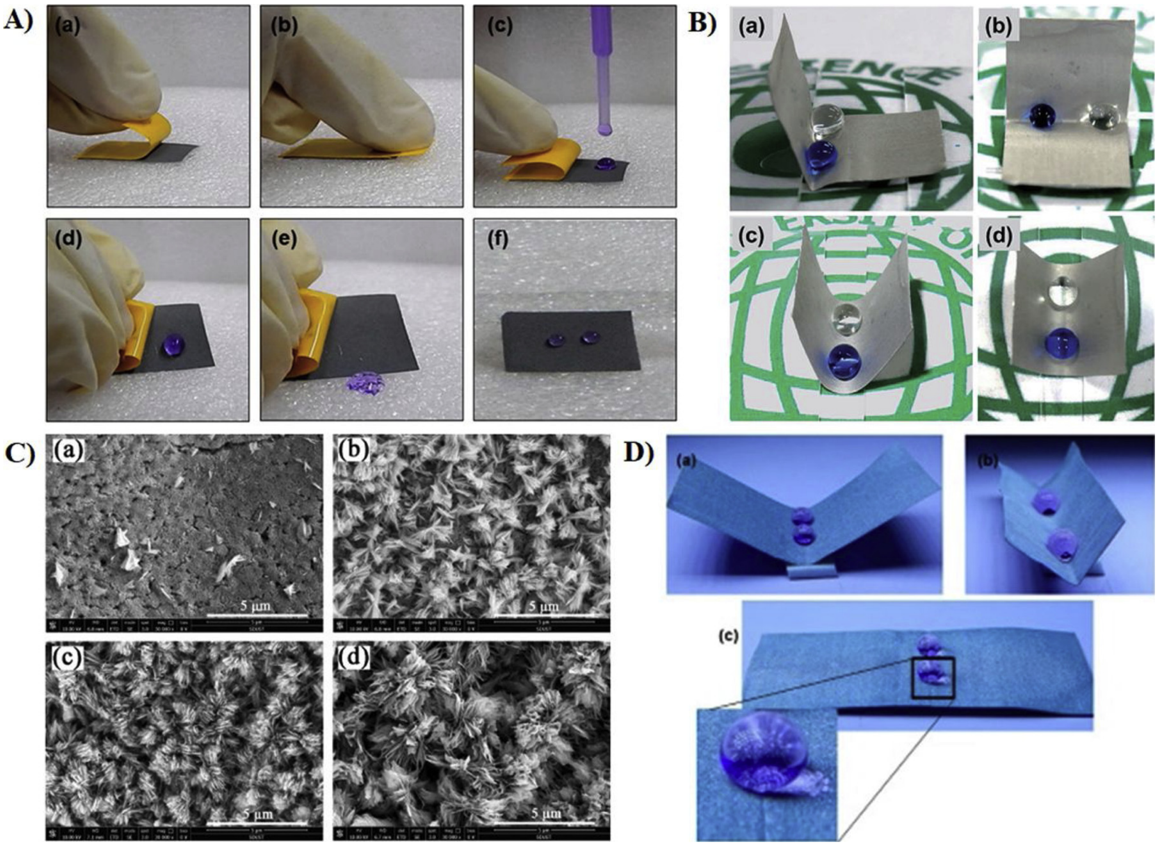

Fig. 4. A) (a–e) Pictures of diverse phases of sticky tape stripping test and (f) microscopic picture of a H_2O droplet on the adhesive superhydrophobic Al surface subsequent to 60 times of stripping (these images are reproduced from ref. [40], copyright, Elsevier). **B)** Pictures of water drop on the flexible (90°) M-430-SS for 8 h film at diverse views (a) cross view, (b) a front view; flexible M-430-SS for 8 h film $>$ 90°(c) side view, and (d) top view. [42]. **C)** SEM images of the coated film affected with the solution-dipping time periods. (a) 5 min; (b) 15 min; (c) 30 min; (d) 40 min (these images are reproduced from ref. [43], copyright 2015, Elsevier). **D)** Pictures of water droplets on a flexible (about 90°) superhydrophobic aluminum film; (c) picture of H_2O droplets on the superhydrophobic aluminum surface subsequent to curving at 180 ° and let it back to the initial shape (this image is reproduced from ref. [41] copyright 2017, MDPI AG).

chemical etching method. The superhydrophobic surface with water CA of 170° and SA of 4° were achieved. The superhydrophobic surfaces recoiled from the high-speed water jet, signifying the outstanding water-repellent ability of the coated surface. The film preserved its superhydrophobicity after undertaking 100 cycles of the sticky tape stripping test. The superhydrophobic behavior survived 90° and 180° of curving temperature, and repetitive folding and de-folding (Fig. 4**D (a–c))**. In addition, the coating exhibited a significant SC property [41].

Calia et al. conducted an investigation on the SC efficiency and the performance of photobleaching of Rhodamine B [44]. This study on fracture-free and similar films determined an exhibition of a great bonding to limestone and reported that the durability checks of treated surfaces displayed nearly unaffected Ti/Ca ratios and SC efficacies. The study also involved large adhesion failures, where the reduced Ti quantities were observed, and coatings were fissure particularly on the surface of the compressed limestone, together with a decreased SC capacity. An effective multidimensional technique has been established to produce robust, superhydrophobic surfaces on a wide range of materials, including wood, cotton, textiles, metals, and glasses. The modification of this method provides a facile and efficient way to manufacture mass-producible, mechanically robust, and robust superhydrophobic surfaces with diverse applications [45].

1.2. Parameters influence the durability studies of SCT

The durability studies of various materials can be influenced by many factors. Some major factors that affect the SCT durability are classified and presented in Fig. 5.

Metal corrosion (oxygen and moisture) is causing a serious issue to the performance of SCT. The SC-superhydrophobic surfaces are mainly used in airplane, vehicles, pipelines and marine ships for a wide range of applications. A fundamental knowledge on how to construct such surfaces using a non-complicated approach and about the surface properties such as morphology, roughness, surface chemistry, surface wetting, and robustness are substantial [46]. Vazirinasab et al. studied about the corrosion resistance of superhydrophobic coatings for metal surfaces such as Al, Cu, Mg, and steel. The study concluded that such phenomenon causes waste of natural resources and also degrades the infrastructure [47]. The development of corrosion immunity among these metallic surfaces is a significant application of superhydrophobic films. Yao et al. [48] showed that the developed superhydrophobic Cu surface exhibits improved resistance against corrosion and durability. Fang et al. reported that superhydrophobic films can efficiently improve the resistance of the metal surface against corrosion hence, increasing the possibility of utilizing superhydrophobic coating as a replacement for chromate-containing treatment films to immune metallic surfaces [49]. Under severe operational environmental conditions Al undergoes surface destruction. Zheng et al. developed a corrosion-resistant SC with an application of a stable superhydrophobic coated film on an Al surface that prevents the creation of ice-covering film [50]. Superhydrophobic multilayer coatings are tuned and swapped into film wettability and redox catalytic corrosion resistance application. The corrosion immunity of the coating remained steady even after 240 h of contact. This improvement resulted due to the superhydrophobicity and the anodic shift in the corrosion potential [51]. Many researchers studied the stability, and durability of the superhydrophobic films that are

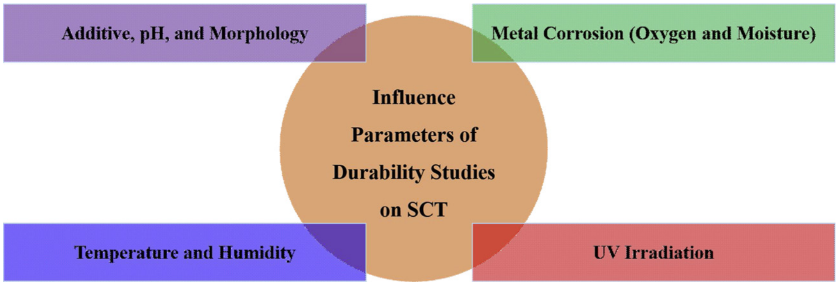

Fig. 5. Parameters influence the durability studies on SCT.

coated on diverse metallic surfaces in water and numerous other organic-aqueous solutions. The stability of superhydrophobic surfaces over an extensive pH-range are crucial for different manufacturing applications [52]. Isimjan et al. studied the influence of water, chloroform and decane on the CAs of titanium dioxide/Silicon dioxide treated steel substrates where the measurement was done every 24 h for a period of eight days [53]. It was observed that CAs remained same, and the surfaces had a steady state that remained for 8 days.

The stability of SC superhydrophobic coatings against UV exposure is crucial, particularly for outdoor surfaces that face exposure to UV light. This is another problem that needs consideration while investigating the durability of the SC superhydrophobic surfaces. Several papers were reviewed and it was concluded that most of the SC superhydrophobic films remain constant while others required UV exposure for stability. Moreover, some SC superhydrophobic films have lost their superhydrophobicity under UV exposure for two hours and also the water CA was decreased from 160 to zero degree [52]. Despite their numerous outstanding characteristics comprising chemical resistance, high resistance to shrinkage, ability to cure at low thermal energy without the presence of volatiles, once epoxy resins are subjected to UV rays, it gets damaged and their durability is decreased significantly [54]. However, Gao et al. reported on the development of highly transparent and ultraviolet-resistant superhydrophobic arrays of silicon dioxide-coated with zinc oxide nano-rods [55]. Recent studies showed that high temperature generally decreases the durability of superhydrophobic coatings that leads to an irreversible changing from hydrophobic to the hydrophilic character [55]. The stability and humidity of superhydrophobic wood were investigated for moisture and temperature aging conditions. Fractures in superhydrophobic coating were investigated after aging with 20 cycles [56,57]. Some of the research groups have reported that there was no significant change in superhydrophobicity after 60 or 90 days; this shows strong stability and durability against humidity [52].

2. Fabrication of self-cleaning surfaces

This section covers a review of the most essential results that were revealed out from durability studies for SCT, that are rendering the fabrication methods. Different types of material have been used to prepare SC superhydrophobic surfaces. Moreover, numerous techniques for the treatment of superhydrophobic surfaces were examined and reported in recent years. Several fabrication techniques were used for the treatment of rough films such as mechanical stretching, sol-gel process, layer-by-layer assembly, chemical and electrochemical depositions, chemical vapor deposition, etching, and lithography [22–26]. The details of various methods involved for the fabrication of durable self-cleaning surfaces were discussed in the further sections (Fig. 6).

2.1. Dip-coating technique

The dip-coating technique can be categorized into five phases, such as dipping, start-up, deposition, drainage, and evaporation. The outcome of these stages of the dip-coating technique gives uniform high-quality films including large and complex shapes of different sizes [58]. A high-quality, cost-efficient, low-thermal energy, low-pressure process that can develop rough surfaces on a diversity of oxides as a sol-gel procedure has been investigated and studied. Sol-gel technique is a multi-step process and it has several advantages over other techniques and for which researchers have paid more attention towards the fabrication of superhydrophobic surface using the dip-coating technique. Sundaresan et al. developed a nano TiO_2 cotton fabrics by sol-gel technique [59]. The technique investigated the significant functional activities namely, antimicrobial, UV protection, and SC. The durability test was carried out in the range of 32–36 washing cycles for the antimicrobial properties. Kumar et al. synthesized mechanically vigorous films using TEOS and glycidoxypropyltriethoxysilane by using the sol-gel method [60]. It was reported that these coatings were capable of maintaining hydrophobicity even after the removal of the upper surface by accelerating scrape. These films demonstrated approximately about 96% SC efficiency. The established deposition method was simple, cost-efficient, and meant for large outdoor applications that require mechanically robust and durable SC properties.

Satapathy et al. [61] synthesized SiO_2 nanoparticles by using a dip-coating technique that entrenched linear low-density polyethylene (LLDPE) superhydrophobic films on glass surfaces. Durable superhydrophobic coatings with excellent SC property were studied and fabricated. They reported comparative studies of porous and non-porous LLDPE/SiO_2 films and their performances. Furthermore; they also noticed that porous coatings exhibited better durability than the non-porous coatings, and showed great industrial application potential. The PBZ/TiO_2 modified polyester of non-woven fabrics were prepared by simple dip-coating and subsequent thermal curing technique which resulted in outstanding mechanical durability and strong immunity to UV exposure. These durable superhydrophobic fabric were effective for separating oil/water combinations by gravity with high separation efficacy [62]. Lee et al. [63] reported that novel surface roughness and micro/nano double-scale surface of networks were fabricated by liquid processed nanoparticle coating. These structures were enhanced and it achieved greater surface properties in both hydrophobicity and translucency showing a high value of H_2O CA and low SA. These features allowed excellent transparency and SC ability as well as a larger waterproof capability. The feature of SC superhydrophobic and water impacts tests are presented in Fig. 7 **(a–c)**.

2.2. Chemical Deposition/Electrodeposition

In the last decade, the electrodeposition and chemical deposition techniques played a significant role in the design and development of novel and advanced superhydrophobic surfaces and devices. The physical deposition and physical vapor deposition techniques were mainly used for the SC superhydrophobic surfaces. By using these techniques, a number of researchers studied the improvement of materials behavior in nanotechnology to develop and design advanced novel SC application which is supportive for life activities. Graziani et al. studied photocatalytic activities of titanium dioxide (TiO_2) films that are used for clay brick surface subsequent to deposition and aging procedure [65].

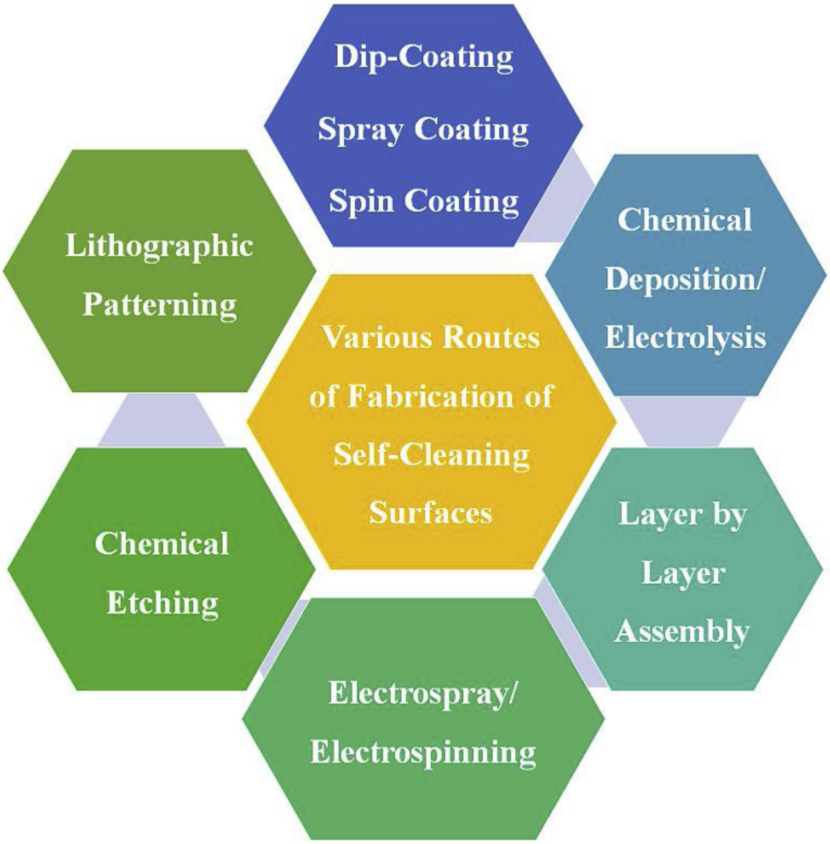

Fig. 6. Various routes of fabrication of self-cleaning surfaces.

The results of their study showed that, the photocatalytic ability of TiO_2 continued to be stable after ageing, thus TiO_2 displayed acceptable photocatalytic ability when it is deposited to the clay brick surface. Their durability towards organic dye was investigated by ultraviolet alone and with wet and dry cycles. Khorsand et al. fabricated an excellent hydrophobic Ni film with the micro-nano network by electrodeposition technique and superhydrophobic surface also showed outstanding lasting durability in 3.5 wt.% sodium chloride solution [66]. Anderson et al. developed revolutionary research in nanotechnology which is based on a new inexpensive and high-quality technique to synthesize distinctive nanostructures which can degrade organic matter when getting in contact with light, and directly onto textiles [64]. Based on such research, it is being made possible to replace the washing machines with a little bit of sunshine. This development places a robust basis for the forthcoming creation of fully SC textiles. The deposition of copper and silver using an electrodeless process that results in the creation of nanostructure quasi-spherical copper (a1–a3) and silver (b1–b3) particles coated on single threads of the cotton; representative SEM images of the fabric surface are shown in Fig. 7D.

A graded micro/nano-network translucent superhydrophobic polytetrafluoroethylene coatings were prepared on the glass surfaces by aerosol-assisted chemical vapor deposition (CVD), showing a H_2O CA of 168°, a water SA that was less than 1° and transmittance to visible light that was higher than 90%. The films showed SC and anti-corrosion properties [67]. The CVD technique is mechanically practical as it can achieve the desired thickness at atmospheric pressure with a well precise controlled stoichiometry. The enhancement, challenges, and prospects of CVD at atmospheric pressure on vanadium dioxide structures were considered [68].

2.3. Layer by layer assembly

The deposition techniques of fabricating thin film are significant in producing useful materials for diverse applications in different types of fields. The layer-by-layer assembly of nanoscale films established powerful and rising attention to the development in the obtainable resources and manufacturing technologies [69]. The fabrication of durable surfaces by using the nano-particle filling method that uses a simple process to make anti-icing polydimethylsiloxane superhydrophobic surface on glass [70]. Yong Li et al. invented an environmentally safe, versatile and efficient method for SC films by using the self-assembly of reformed porous chain-like silicon dioxide nanoparticles [71]. The superhydrophobic coatings simply and rapidly restored a few cycles after the damage has occurred; this provides a strategy capable of challenging low durability. The antifouling ability of the superhydrophobic coating was tested and it is presented in Fig. 8**A**.

Qu et al. obtained mechanically durable superhydrophobicity by reproducing the lotus leaf's ability of auto restoring μ-networks and restoring hydrophobic wax layer [75]. The as-prepared material is not only mechanically durable but also can be developed by the surface scrape. The mechanical adhesion of both dense and mesoporous titanium dioxide films are not altered by the local and ecological enduring. Though, enduring has effects on the initial CA, efficiency, concentration, the degeneration rate and the surface composition [76]. Cost efficient synthesis of large-scale ultra-durable superhydrophobic films was attained by fast template-free micro nanotexturing of IPNs. The yielded films demonstrated exceptional anti-AR upholding superhydrophobic water CAs in addition to a virgin lotus effect on SAs of a value lower than 10° for up to 120 continuous scrape cycles. This sprayable polyurethane-acrylic solution and surface texture provide a fast and cost-effective method for the surface-independent manufacture of ultra-durable, translucent self-cleaning surfaces with a superior scrape, chemical, and ultraviolet exposure immunity [45]. The micrographs

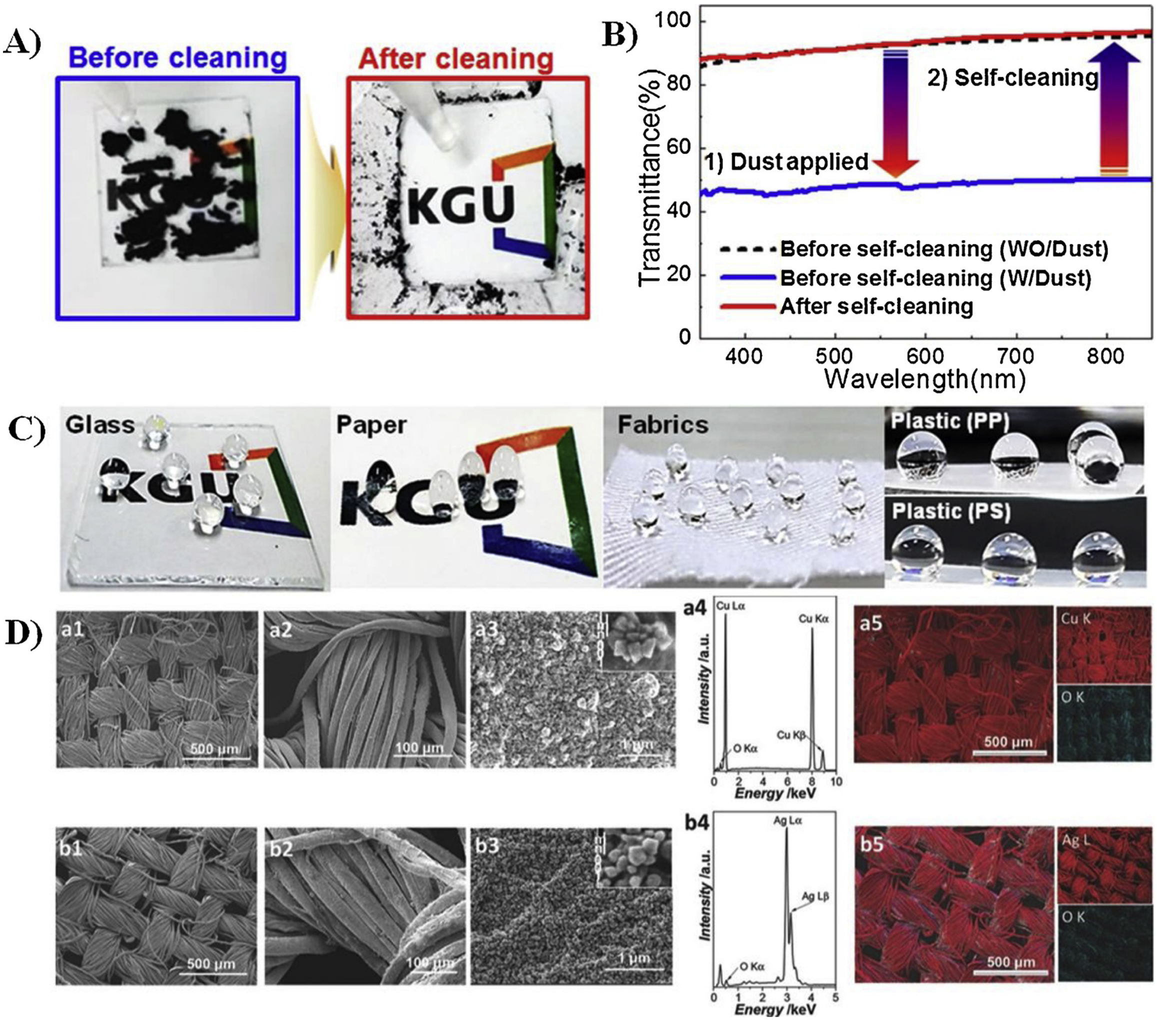

Fig. 7. **A)** The SC ability of the enhanced non-wetting nano-particles coatings and the multipurpose application of the nano-particle films, images of the SC test with pristine and nano-particles-treated glass before (blue line) and after (red line) SC. **(B)** The effectiveness of nano-particles-coated films in transmitting radiant energy before SC with no C dust (black line), before SC with C dust (blue line), and after SC (red line). **(C)** Images of H_2O droplets on numerous nanoparticles-coated surfaces: glass, paper, fabric, and plastics (these images are reproduced from ref. [63] copyright 2016, IOP publishing). **D)** (a1–a3) SEM images of copper@Cotton, a4) EDX spectrum acquired from scanning area shown in (a1, and a5) layered map image acquired from EDX comprising element mapping of copper and oxygen. (b1–b3) SEM pictures of silver@Cotton, b4) EDX spectrum acquired from scanning area shown in (b1, and b5) layered map picture acquired from EDX comprising element mapping of silver and oxygen, (these images are reproduced from ref. [64] copyright 2016, John Wiley and Sons, Inc. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

showing the result are presented in Fig. 8**B**.

2.4. Spray coating

Silica nanoparticles and dodecyltrimethoxysilane were coated on glass and stainless-steel surfaces by using brush-coating, dip-coating and spray-coating approaches for SC and highly effective oil/water separations [77]. Superhydrophobic - self-cleaning surfaces were obtained by using a mixture of cool orange-gray paint which was coated by spraying on the fiber cement boards with white basecoats [78]. The transparent, stable and robust superhydrophobic surfaces were treated by a simple spray deposition procedure. The superhydrophobic surfaces showed excellent stability under pressurized jet water, ultraviolet radiations and abrasion. These unique fabricated surfaces produced a promising candidate for outdoors SC applications [79].

2.5. Spin coating technique

A combination of hydrophobic silica particles and polystyrene were used for the preparation of superhydrophobic silica coatings by a spin coating deposition procedure. The durability and anti-corrosion feature of superhydrophobic film was demonstrated by using resistance to water jet impact and corrosion tests in 3.5% sodium chloride solution with long dipping time [80]. Photocatalytic silicon dioxide-titanium dioxide films on polycarbonate were prepared by using the spin-coating technique for SC applications. It was described that a very thin water film made on the superhydrophobic surface can simply clean-off the dust particles while flying [81].

2.6. Electrospray/electrospinning coating technique

The polystyrene/Al_2O_3 nanocomposites superhydrophobic coatings were prepared by new electrospinning procedures. The effect of the electrospinning factors on morphology, surface roughness, and wettability tests was studied on these coating at different techniques [82]. Superhydrophobic coating was prepared for electro-spun ultrathin fibers and electro-sprayed nanostructure silica micro-particles for easy emptying packaging applications [72]. The step-by-step methodologies followed to organize the nanostructure multilayer LDPE/PCL/SiO_2 film are presented in Fig. 8**C**.

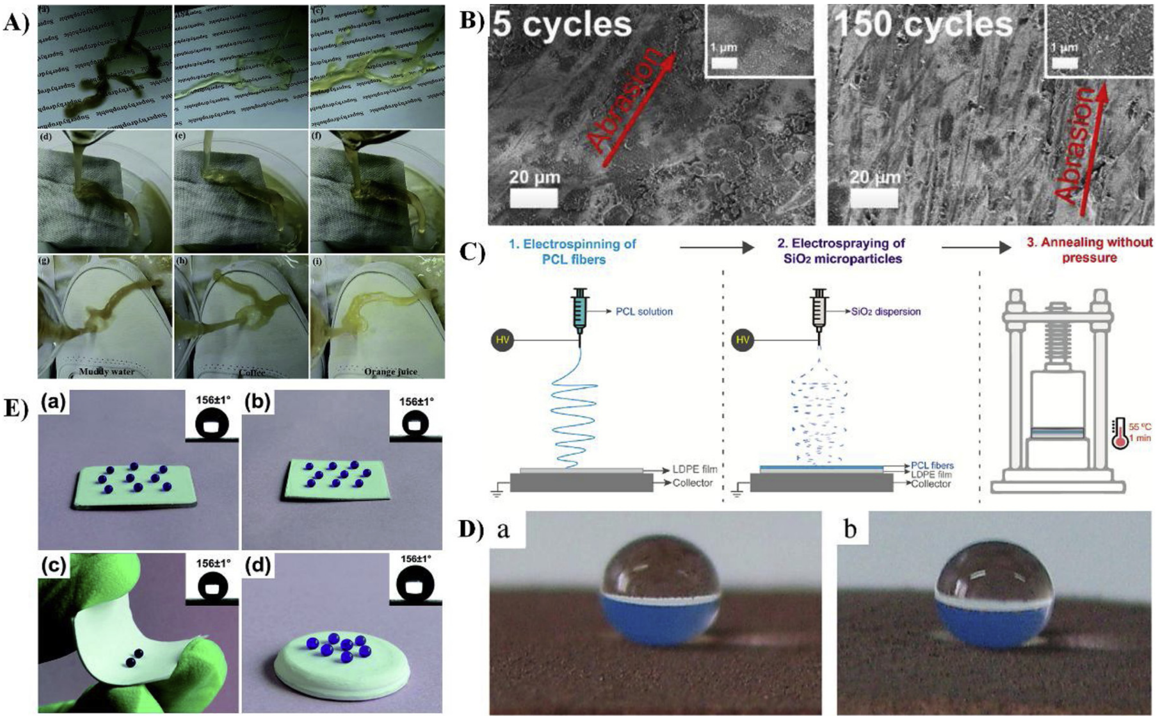

Fig. 8. **A)** Three conventional solution-like pollutants comprising cloudy H_2O, coffee, and orange juice stained on treated superhydrophobic paper, fabric and shoe surfaces, respectively, to exam the anti-contamination capability of the superhydrophobic film that is reproduced from ref. [71] are reproduced from copyright 2017, RSC. **B)** Intermediate cyclic damages of the Pu-PMMA-F-SiO_2 coating from the 5th cycles up to the 150th cycle, with negligible damages to the IPN-F-SiO_2 (images are reproduced from ref. [45], copyright 2015 Elsevier), **C)** Diagram demonstrating (1) an additive manufacturing of the poly(ε-caprolactone) (PCL) fibers which is electrospun on low- mass per unit volume polyethylene (LDPE) film, (2) fabrication of the silicon dioxide micro-particles that is electrosprayed on the surface of LDPE/PCL film, and (3) thermal annealing of the LDPE/PCL/SiO_2 coat with a hot press with no external force, images are reproduced from ref. [72]. copyright 2015, MDPI. **D)** Dampening images of Cu-based materials: (a) freshly-prepared sample, (b) the sample is 10 months old; these are reproduced from ref. [73], copyright 2015 Elsevier. **E)** Pictures of H_2O droplets that were treated with methylene blue dye on numerous surfaces: (a) glass slip, (b) cardboard, (c) a bent thick plastic film and (d) a free-standing molded superhydrophobic material, these are reproduced from ref. [74], copyright 2015, RSC. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.7. Chemical etching technique

The superhydrophobic films on brass surfaces were prepared by a chemical etching technique with an amalgamation of two etchants namely, HCl and HNO_3. The durability of these coatings was detected by performing chemical, thermal, and mechanical stability tests and also the coatings exhibited SC and anti-fogging properties [83]. Actually, the yellow SC superhydrophobic polycarbonates were manufactured by simple HNO_3 treatment and MTCS (methyltrichlorosilane) functionalization, where the yellow superhydrophobic SC was easily systematized by controlling dipping time in HNO_3 and showed mechanical stability and SC properties [84].

2.8. Lithographic patterning technique

A non-complicated and dynamic technique that was developed to create distinct graded micro/nanostructures over large areas was fabricated by photolithography and reactive ion etching. These coatings showed a reproducible way to design and manufacture superhydrophobic surfaces; these hierarchical structures were applicable to self-cleaning surfaces [85]. Han et al. fabricated and enhanced superhydrophobic tungsten hierarchical surfaces that survived 70 scrape cycles, 28 min of solid particle impact or 500 tape stripping cycles to keep CAs of larger than 150° and SAs of lower than 20° during durability test [86]. This explains its possibility to accomplish high durability of the superhydrophobic surfaces for practical applications.

2.9. Miscellaneous techniques

The long-term durability of superhydrophobic is practically significant for SCT [87]. The fabrication of a non-complicated and environmental friendly technique of Cu-based superhydrophobic materials was produced. A wetting image of one of the freshly prepared Cu-based blocks is presented in Fig. 8**D a)**. The H_2O droplets continue to display a spherical shape and the CA is 153.1° and the RA has lower than 8° when the same sample was put in the air for 10 months. Fig. 8**D b)** shows that the superhydrophobic as-prepared Cu-based material surfaces have long-lasting durability [73]. Zhi et al. reported a non-complicated manufacturing technique of a durable superhydrophobic top surface that was strongly attached to the surface *via* a middle linking film [88]. The outcomes of scrape test indicated that the surface can bear up to 180 scrape cycles on 1200 CW sandpaper under 2 kPa applied pressure. Mechanically durable polysiloxane superhydrophobic surface was prepared effectively by using polymerization of silanes blending with particles [89]. The as-prepared polysiloxane surface displayed stable superhydrophobicity even after the surface experienced prolonged friction. The recyclable SC- superhydrophobic materials were prepared by using surface-functionalized quartz sand particles implanted into polyvinyl chloride. These materials show good superhydrophobicity under 5H pencil hardness test which was maintained even after 500 cm abrasion test loaded into 500 g [74]. The surfaces of as-prepared superhydrophobic material that was fabricated on numerous surfaces have the static water CAs of 156 ± 1°, as presented in Fig. 8**E (a–d)**. Table 1 illustrate the various methods used for SCT and their properties and potential applications.

Table 1
Various methods of developing durable self-cleaning surfaces and their properties.

Methods	Samples	Properties	Ref.
Dip-Coating technique	1. Nano TiO_2-cotton fabrics	antimicrobial, ultraviolet protection, and self-cleaning	[59]
	2. TEOS and glycidoxypropyltriethox ysilane	Durable, hydrophobic, and self-cleaning	[60]
	3. SiO_2 nanoparticles- low-density polyethylene (LLDPE)	Durable, superhydrophobic, and self-cleaning	[61]
	4. PBZ/TiO_2-polyester of non-woven fabrics	Durable, UV resistance, and self-cleaning	[62]
Chemical deposition/ Electrolysis	1. TiO_2-clay brick	Durable, UV resistance, and self-cleaning	[65]
	1. Ni film	Durable, superhydrophobic, and self-cleaning	[66]
	2. Copper fabrics	Durable, Organic dye degradation, self-cleaning	[64]
	3. Polytetrafluoroethylene	Transparent, self-cleaning, anti-corrosion	[67]
Layer by layer assembly	1. Polydimethylsiloxane	Anti-icing, superhydrophobic	[70]
	2. Porous chain-like SiO_2 nanoparticles	Durable, Anti-fouling, superhydrophobic	[71]
	3. Mesoporous TiO_2 films	Durable, self-cleaning, photo-catalyst	[76]
	4. Polyurethane-acrylic solution	Durable, self-cleaning	[45]
Spray coating	1. SiO_2 nanoparticles-dodecyltrimethoxysilane	Durable, self-cleaning, oil-water separation	[77]
	2. Cool orange-gray paint	Transparent, stable, robust, superhydrophobic	[78]
Spin coating	1. Hydrophobically treated SiO_2 particles and polystyrene	Durable, Anti-corrosion, superhydrophobic	[80]
	2. SiO_2-TiO_2 films	Superhydrophobic, self-cleaning	[81]
Electrospray/ Electrospinning coating	1. Polystyrene/Al_2O_3 nanocomposites	Superhydrophobic, self-cleaning	[82]
	1. LDPE/PCL/SiO_2 film	Superhydrophobic, self-cleaning	[72]
Chemical etching	1. HCl-HNO_3-Lauric acid	Superhydrophobic, anti-fouling, self-cleaning	[83]
	2. HNO_3-MTCS	Durable, superhydrophobic, and self-cleaning	[84]
Lithographic patterning	1. Tungsten	Durable, superhydrophobic, and self-cleaning	[86]

3. Durability of SCT with recent applications

The durability of the photocatalytic property was measured throughout a year of outdoor contact test and 2000 h of speeded ageing in a chamber with ultra-violet exposure and evaporation cycles. The outcomes demonstrated that, the photocatalytic property has been unchanged on concrete, however on sandstone subsequent to artificial ageing, it was decreased because of the elimination of nanoparticles from the surface [90]. The recent progress of SC superhydrophobic surfaces was studied with help of strategy, and the development of materials [91]. This consideration of prospectus was critically reviewed and the altered types of self-cleaning surfaces, fabrication techniques, working mechanisms, and their applications used globally and studied for different industrial application were highlighted [92]. Jeevahan et al. presented a comprehensive review on some of the recent works in the preparation of superhydrophobic surfaces, their possible applications, and the challenges confronted with their new applications [93]. Recently, more studies concentrating on the investigation of SCT for different advanced applications were revealed by the literature.

3.1. SC building

The nanomaterial of titanium dioxide and silicon dioxide are mostly used for construction. These are the main challenges to improve properties like strength, durability, bond strength, corrosion resistance, and AR. Durable SC coatings for architectural surfaces that incorporate titanium dioxide nano-particles into hydroxyapatite films were studied as a potential course to provide marble with durable SC aptitude and mechanical support [98]. It is a great challenge to construct a building with SC coating activity. Using a simple and inexpensive process, superhydrophobic and oleophobic building surfaces have been developed [99]. Andaloro et al. reported on the SC efficiency of titanium dioxide and silicon dioxide-based films with cladding materials [92]. Primary experimental examinations were accomplished to confirm the hydrophobic and hydrophilic behavior proceeding to the outdoor application over the water CA measurements. Afterward, outdoor tests are performed to screen color changing over three years confirming product efficiency and its durability. The different cladding materials treated with the sol product varieties and their SC performance observed over three years. Sols that were applied for compressed spray coating methods are presented in Fig. 9**A**. Recently, Amorim et al. studied the possibility of developing an efficient and durable SC acrylic paint containing mesoporous titanium dioxide microspheres. According to the cycling tests, paint containing $MTiO_2$ exhibited good photo-activity when compared to commercially available paint [100].

3.1.1. SC toilets

Maric et al. established and fabricated SC toilets for commercial application [101]. They concluded from their study that, the public bathrooms are problematic to be kept uncontaminated and it is also difficult to periodically check the cleanliness of the place. The problem was solved by developing an intelligent design of a self-operating cleaning system that could be retroactively tailored into a diversity of toilet seats. The durability examination showed that the device is capable of surviving the surroundings of the working environments commonly associated with public lavatories.

3.1.2. SC mineral paints for architectural heritage

Pal et al. [102] developed mineral silicate paint to be used in architectural heritage, enhancing the durability. In this study, potassium silicate (K_2O_3Si) was suggested to serve as a binder agent to provide strength, adhesion, and durability to the concretes and stone. The SC property of the mineral silicate paint was evaluated by the photobleaching of organic dyes after solar light exposure. SC activity was compared with the organic binder-based paints and commercial established paints that are highly operational stable. Fig. 9**D** shows the image of a droplet of rhodamine B dye on three different types of painted surfaces. Moreover, the figure shows the dye interaction with solar light exposure along with the kinetics of photobleaching. The study of Gupta et al. reported that the mineral silicate paint has seven times higher efficacy than the resin and commercially available paints like rhodamine B stain, and four to six times higher efficacy than the methylene blue [97].

3.2. SC photovoltaic devices/solar panel

The SCT was mainly originated from a mixture of photocatalytic oxidative decomposition of organic pollutants and superhydrophilicity originated over the spreading of the water droplets on a titanium dioxide substrate, serving the SC procedure. It was also noticed that most of the photocatalytic influences vanished within 5.5 years of outdoor contact. For dry (waterless) environment, glass has intrinsically a nanostructured surface to avoid settlement of dust particles on the glass substrate allowing H_2O to spread over. Thus, the mixture of SC and

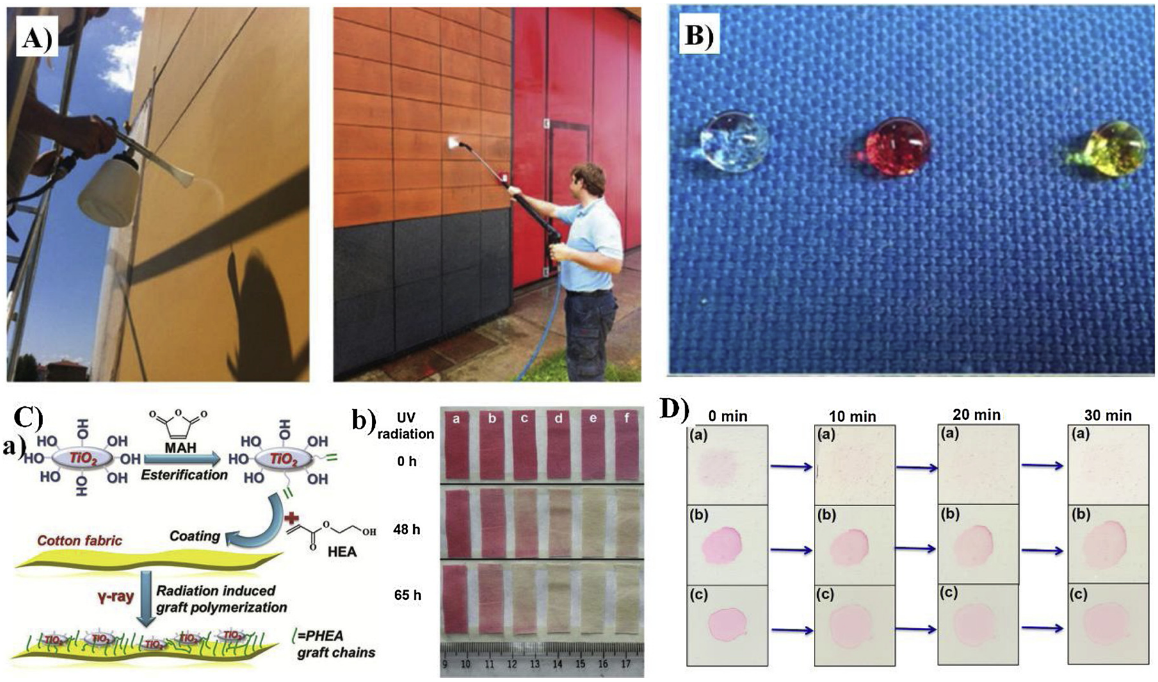

Fig. 9. A) Pressurized spray coating on facade cladding panels (image is reproduced from ref. [94], copyright 2015 Elsevier). **B)** stained PDMS-E-PET textile and (b) printed superhydrophobic PDMS-E-PET textile [95], Procedure of covalently attaching of titanium dioxide Nanoparticles onto cotton fabric, **C)** Staining stability test of the treated cotton fabrics under the ultraviolet exposure (the image is reproduced from ref. [96] copyright 2015. Elsevier). **D)** Photo-bleaching of rhodamine B silicate coting, (**b**) resin coating, (**c**) commercially available coating with solar light exposure (images are reproduced from ref. [97]. Copyright 2015, Elsevier.

antireflective activities with strong durability is most suitable for photovoltaic devices applications [33]. The novel and facile fabrication methods have been invented for future practical application. Besides this routine completed fabrication processes of coatings (dip coating, spray coating, and roll to roll coating) were not suited for mass and large-area fabrication [103,104]. The fabrication coatings should have high transmittance, superamphiphobicity, and excellent robustness so as to utilize in a large spectrum of applications [105]. Han et al. established a non-complicated and readily procedure to alter the cover glasses of the solar panel/photovoltaic system by using the atmospheric pressure plasma treatment procedure [106]. The photovoltaic system was evaluated by using a twenty-day outdoor examination that yields an average of 12.79% conversion efficacy of the pristine glass-covered.

3.3. SC fabrics/ textile industry

The performance of fabrics/textile goods have an imperative effect in our basic needs and in other fields such as agricultural and health sectors. This has led an ongoing development and invention in the area of nanotechnology related to the textile industry. In the recent years, many researchers are concentrating on research that focuses on the usage of nanotechnology in the fabrics/textile industry with a high success rate. Presently, nanotechnology is used to improve textile qualities, such as smoothness, durability, fire retardancy, breathability, yarns and water repellency [107,108]. Researchers mainly concentrate on some of the innovative methodologies that allow the manufacturing of high value-added textiles providing consumers with better level of safety, aesthetics, comfort, and functional performance [109]. Researchers have designed and developed a SC cloth combining of nanotechnology and multipurpose chemical finishing. Based on lotus leaf concept, researchers established a new concept about SC and a textile surface with self-cleaned system. Gupta and Gulrajani [97] reported on the development of self-cleaning surfaces for textiles and cotton fabrics [110].

A group of scientists from the Indian Institute of Technology Delhi (IITD) have developed a Nanocomposite fibers with unique features of SC, dyeability, toughness, thermal stability and electrical conductivity depending on the type of nanomaterials used internally during the production such as carbon nanotubes, nano-clays, and silica or titanium nanoparticle [111]. IITD researchers are currently developing nanocomposite coatings on textile and nanofibers based on polymer nanocomposites for production of functional textiles with improved durability and performance. Simultaneously, Wu et al. predicted that the durability of dry-wash will offer motivation for the use in difficult or delicate circumstances [112]. Yu et al. reported that titanium dioxide nanoparticles were covalently attached to cotton fabrics, initially by esterification with MAH (maleic anhydride), and then co-grafting with HEA (2-hydroxyethyl acrylate) under γ-ray irradiation as depicted in Fig. 9**C** [96]. They demonstrated the enhancement of washing durability experiment. This was carried out to assess the adhesion force created by the covalent bonds between titanium dioxide nanoparticles and cotton fabrics, anchored by PHEA graft chains. Further characterizations were carried out showing titanium dioxide nanoparticles attached to the cotton fiber surface after thirty expedited times of washing. Finally, they concluded that the photocatalyzed SC ability to functionalize cotton fabrics was well-retained [96]. The coating showed an outstanding ability to withstand organic solvents; an aqueous solution of acid and base, and frequent washing. It was evident that this superhydrophobic coating can be used for development of functional fabrics for numerous implementations such as individual protective clothing. The coated films were durable to endure a hundreds of washings. Furthermore, they have exceptional reliability against extended soaking times of organic solvents, and acidic/base solutions [113]. A multi-operational superamphiphobic cotton fabric was created by immobilizing silica nanoparticles on the surface of the cotton fabric and additionally was modified by 1H,1H,2H,2H-perfluorooctyl trichlorosilane (FOTS) where the interfacial free energy of the fabric composite was lowered by incorporating FOTS modifier. They also showed the treated cotton fabrics to have high liquid resistance towards water, colza oil and n-hexadecane with reduced surface tension, and CA of 158°, 152°, and 153°, respectively. The superamphiphobic cotton fabric possesses controllable outstanding mechanical and chemical durability, SC, self-healing property, and can be used for practical applications [114].

The superhydrophobic polyethylene terephthalate textile surfaces with a SC property was formed by preparing the microscale fibers with alkali and then subsequently treated with polydimethylsiloxane. Wettability tests revealed that the superhydrophobic textiles were against immune acid/alkaline etching, ultraviolet exposure, and extended washing. The dyed or printed superhydrophobic PET (ethylene terephthalate) textiles with superhydrophobic surfaces are shown in Fig. 9**B (a, b)** [95].

3.4. SC in other applications

SCT is also used in other various applications such as anti-corrosion and anti-fouling coatings, Anti-icing in aerospace, wind blades, turbines, anti-freezing coatings, anti-reflective and transparent substrate fabrications [115–121]. In addition to these applications, SCT can also be applicable for the separation of oil-water and oil-emulsion separations, cell adhesion and controlled drug release applications [116,122,123]. Owing to the excellent self-cleaning nature of the coating materials and surfaces, the SCT showed much interest in various kinds of applications.

4. Flexible self-cleaning materials and applications

In the very recent days, flexible self-cleaning surface is one of the trending topic due to wide usage of the surface on various applications such as electronic devices, wearable devices and sensors, anti-reflective coating, anti-fouling and smart drug release, membrane, and superhydrophobic coatings and films [124–128]. Flexible and wearable devices with cleaning ability of surfaces for a prolonged time is the most deserving property for the industrial applications. The major drawback of flexible self-cleaning is the loss of self-cleaning property over a period of usages or post to several bending cycles. The drawbacks can be overcome by enhancing the stability and durability of the flexible self-cleaning surface [128,129]. Recent researches were focused on enhancing the mentioned properties and used for a variety of applications. Li et al. developed a novel smart coating material for the fabrication of flexible superhydrophobic surface [124]. The coating solution was prepared by dispersing the multiwalled carbon nanotubes and magnetic nanoparticles (Fe_3O_4) in thermoplastic elastomer solution and spray coated on various substrates such as glass, copper, PET, and cloth followed by ethanol treatment. The fabricated substrate showed excellent superhydrophobic and self-cleaning property and maintained the flexibility. Moreover, the fabricated substrate also showed excellent sensing ability under bending, stretching, and torsion. Following the surface property of cicada wings, a transparent and flexible self-cleaning broadband anti-reflective film was developed [125]. Děkanovský *et* al. developed a highly flexible PDMS and polypyrrole (PPy) composite with superhydrophobic and self-cleaning property. The prepared membrane- film showed excellent flexibility, anti-fouling and drug releasing behavior [126]. Wu et al. fabricated a highly flexible and robust self-cleaning coatings using a fluorinated silica nanoparticle modified with polydimethylsiloxane (PDMS) [127]. The coatings fabricated substrate showed excellent drag reduction behavior and maintained the self-cleaning behavior under severe mechanical and abrasion test as well as strong acidic and basic conditions. Xu et al. fabricated a flexible superhydrophobic biomimetic surface by deposition of monodispersed polystyrene (PS) spheres; casted PDMS pre-polymer and UV treated before depositing the silver film on the surface [128]. The fabricated substrate expressed the excellent flexibility and maintained the superhydrophobic self-cleaning behavior.

5. Outline and future views

This critical literature survey discusses the recent developments in research and the promising efficiency, stability, and durability of SCT. At present, the drawbacks of having poor mechanical strength and inability to withhold the surface property under severe environmental changes, usage of hazardous chemicals, high cost, and longer processing time could lack the usage of the self-cleaning surface property for several applications. The main objective of this literature survey is to explore the most efficient and durable SC superhydrophobic structures. The techniques developed in the last five years such as dip-coating/sol-gel, CBD, CVD, spray coating, electrospray/electrospinning coating, spin coating, chemical etching, lithographic patterning, electrolysis, layer by layer assembly and miscellaneous were reviewed. SC superhydrophobic technology with multifunctional applications has attracted great attention in recent years to various industrial applications such as solar cell, SC toilet, textile industry, cotton fabrics, building constructions. Our critical personnel perspective and the need of future development in the field of SCT is to ley by focusing on the development of reliable methods featuring ease to handle, cost-effective, stable and durable for SCT applications. SCT still suffer from numerous complications such as low mechanical stability, high cost raw materials particularly used for multi-functionalities, moderate efficiency, low durability, and scalable production stability, and underdeveloped measurement methods for adhesion to the SC- superhydrophobic. Thus, developing flexible, bendable, renewable, and efficient responsive SCT is a significant issue for future investigation. A typical applications based on durability for SCT were summarized and discussed in this review.

With due expectations, the SCT development program might get more attention from the researcher in the near future and also people might not need to wash their clothes because of nano-enhanced textiles with self-cleaned feature. The preparation methods of self-cleaning surfaces should minimize the use of organic solvents and fluorochemicals, or the use of low volatile organic compounds to avoid any possible environmental health hazards. The durability of SC techniques in laundries, textile and building construction is continuously improving. The nature will continue to inspire with great ideas for development of user-friendly and cost-effective methods to construct self-cleaning surfaces with superhydrophobic for innovative applications with enhanced durability. The introduction of self-healing or stimuli-responsive surface property on the SCT would also improve the durability and stability of the coated materials. The continuous thrust on the development of new technologies and easy curable coating with superhydrophobic self-cleaning are highly needed for further developments in this field. In addition, flexible self-cleaning surface property also becoming interest in the recent days, so that, more interesting applications in the flexible self-cleaning surfaces need to be focused deeply in the coming years in order to use the surface property for wider industrial applications. It is strongly evident that novel synthesis methods with cost-effective and high quality must be a continuous target for researchers and industry.

6. Conclusions

In this critical review, we have counted the latest achievements related to durability of SCT, collected by their practical applications such as textile industry, toilet, solar cell, cotton fabrics, building construction, and flexible self-cleaning materials and applications, etc. The improvement in eco-friendly coatings of SCT are enhancing the environmental conditions for long periods of durability by reducing time, energy, laundry cost, etc. Here the recent progression in the durability of SCT was reviewed and discussed. The importance of the SCT in industrial applications needed enhanced stability and durability of the coating surface. In this regard numerous researches were carried out in the recent days for developing multi-functional and robust self-cleaning surfaces with highly stable and durable surface properties. On the other hand, the durability of superhydrophobic surfaces is considered as the most important aspect that should be further strengthened in the future work in this field. The self-cleaning and superhydrophobic self-cleaning surfaces recently used for the flexible and bendable surface fabrications which are used for the wearable devices in electronics and sensors. In addition, the self-cleaning surfaces also focused on anti-fouling and drug release applications, anti-corrosion, anti-icing, anti-snow, anti-freezing, anti-reflecting and transparent surfaces, air-purification, and smart windows. Recent research also suggests that the self-cleaning behavior with hydrophobic and hydrophilic cysteine containing co-ordination polymer would show better adsorption behavior of n-octane and methanol. Current conclusions, future viewpoints, and hurdles in the field of the durability of SCT were discussed in this critical review. It also suggests the importance of the self-cleaning surface with durable and stable surface property with future aspirations.

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