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COMPOSITE MATERIALS - CURRENT STATE OF STANDARDIZATION

KOMPOZITNI MATERIJALI - TRENUTNO STANJE STANDARDIZACIJE

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Abstract

In recent decades composite materials have become widely used across various industries, either alongside traditional materials or as complete replacements for conventional materials and technologies. This shift is attributed to several advantages they offer, such as low mass, chemical resistance, significant load-bearing capacity, strength, adaptability to modern construction principles, and utilisation of new technologies as additive manufacturing. The first composite materials were developed and patented in the late 19th and early 20th century. For more than a century, composites have seen significant progress in terms of types, properties, technologies, and various applications. Consequently, the need for standardized practices has emerged that can only be achieved through the establishment of standards and standardization processes. Both the International Organisation for Standardization (ISO) and the American Society for Testing and Materials (ASTM) have dedicated technical committees and subcommittees focused on standards for composite materials. Each of these organisations has published approximately one hundred standards related to composites, covering terminology, properties, test methods, procedures, and more. The paper provides a concise historical overview of the development of composite materials and outlines fundamental types of composites. Additionally, it presents an analysis of the quantity and content of standards related to composites published by aforementioned standardization organisations. Statistical data regarding the publication of these standards over time and by specific area are also presented. Conclusions have been drawn based on these analyses.

Izvod

Tokom prethodnih dekada, kompozitni materijali sve šire nalaze primenu u raznim industrijama, zajedno sa tradicionalnim materijalima, ili kao potpune zamene za konvencionalne materijale i tehnologije. Ovakva promena je nastala zahvaljujući nekoliko prednosti ovih materijala, kao što su manja masa, otpornost na hemijski uticaj, značajni kapacitet nosivosti, čvrstoća, adaptabilnost ka modernim principima konstruisanja, upotreba u novim tehnologijama, kao što je aditivna proizvodnja. Prvi kompozitni materijali su razvijeni i patentirani u kasnom 19. i početkom 20. veka. Već duže od jednog veka, kompoziti imaju značajnog uspeha s obzirom na tip, osobinu, tehnologiju i raznu primenu. Stoga je nastala potreba za standardizacijom, koja se može ostvariti zasnivanjem standarda i procesom standardizacije. Međunarodna organizacija za standardizaciju (ISO) i Američko udruženje za ispitivanje i materijale (ASTM) su osnovali tehničke komisije i potkomisije koje su fokusirane na standarde za kompozitne materijale. Svaka od tih organizacija je izdala oko stotinu standarda vezanih za kompozite, gde su obuhvaćeni terminologija, osobine, metode ispitivanja, postupci, i drugo. U radu je dat koncizan istorijski pregled i razvoj kompozitnih materijala, sa posebnom pažnjom na osnovne tipove kompozita. Osim toga je data analiza kvantiteta sadržaja standarda vezanih za kompozite, izdatih od strane gore spomenutih organizacija za standardizaciju. Dati su i statistički podaci vezani za izdavanje ovih standarda tokom vremena i s obzirom na specifične oblasti. Navedeni zaključci dobijeni su na osnovu ovih analiza.

INTRODUCTION

A composite is a combination of two or more materials formed on a macroscopic level, utilizing special techniques for mixing and joining. The primary objective is to achieve specific properties that surpass those of the individual materials within the composite's composition. The concept of synergistically joining materials has its roots in ancient times. For instance, as early as 3400 BC, the Mesopotamians glued wooden strips oriented in various directions to create a precursor to today's plywood /1/. Around 2000 BC, ancient Egyptians fashioned an early form of cardboard by bonding layers of paper or linen soaked in a primitive mortar /1/. Successive generations of builders began reinforcing earthen bricks and vessels (1500 BC) with dry grass and straw. In the 12th century, the Mongols refined the technique of crafting composite bows by combining diverse materials, including wood, bamboo, cloth (silk), beef bone, horns, and tendons. These components were fused into a compact mass using coniferous resin, encased in birch bark, and then compressed /1, 2/. This innovation not only enhanced the elastic properties of the bows but also rendered them more durable, powerful, and precise, while also enabling arrows to achieve greater speed and travel distances of up to 450 metres. The resins used for material bonding were primarily of vegetable or animal origin. It wasn't until the 19th century that the first synthetic resins based on polymers were produced, marking the onset of the modern era of composite materials, /2/. At the beginning of the 20th century, plastics as vinyl, polystyrene, phenolic, and polyester began to be produced, gradually replacing natural resins in composite production. In 1907, Leo Hendrik Baekeland synthesized Bakelite /3/. Initially, Bakelite resin was quite brittle, but Baekeland discovered a method to enhance its elasticity, softness, and strength by blending it with cellulose. The first notable application of Bakelite occurred in the automotive industry when it was used to manufacture gear levers for Rolls Royce cars in 1917, /3/. Subsequently, resin production techniques were refined. During the 1930s, polyester resin was developed, gaining popularity in the subsequent era of composite production. However, plastic alone lacks sufficient strength and must be reinforced. In 1935, Owens Corning introduced the first glass fibre, which when combined with a polymer material like polyester resin, yielded a robust yet lightweight composite material known as fibreglass. Carleton Ellis patented unsaturated polyester resin in 1936 /1, 3/, marking the inception of fibre reinforced polymer (FRP) industry /2/. The earliest applications of FRP were witnessed in the 1940s, particularly in the marine industry, where this material replaced traditional materials like wood and metal in boat construction /4/. During the Second World War, the demand for new materials with reduced weight and simultaneously increased strength, durability, and resistance to environmental aggressors (such as atmospheric conditions, salt and fresh water, dust, sand, and soil) for aircraft and vessels became critical. As a result, more than three tons of fibreglass were utilized until 1945, primarily for military and technical applications /3/. After the Second World War, the utilization of composite materials extended to the public sector and consumer goods. For instance, in 1947, the first vehicle with a complete composite chassis was manufactured /1/, and by 1948, anti-corrosion fibreglass pipes were produced for oil industry's requirements /3/. The production and utilization of composites experienced rapid growth from the 1950s onwards. Components of ships, aircraft, vehicles, rocket engines, spacecraft, tanks, pipelines, and household appliances, among others, started being crafted from composites. In the early 1960s, carbon fibre was patented and promptly found widespread use in the mechanical industry and consumer goods. During this period, the shipbuilding industry emerged as the largest consumer of composite materials. In the 1970s, this role shifted to the automotive industry, which continues to be the largest global customer for composite manufacturers /1/. Starting in the 1970s, and throughout the 1980s and 1990s, composites found application in the construction of bridges, initially in individual parts and later in entire structures, /3/. Notably, the Boeing 787 Dreamliner, which made its debut flight in 2009 and received all necessary certifications for commercial flights in 2011 /5/, marked a significant milestone. It is the world's first large commercial aircraft to primarily employ composite materials as its structural foundation. Composites account for 80 % of the aircraft's volume and 50 % of its weight /5/. Over the past decade, the development of composite materials has advanced consistently and rapidly. Their application in various sectors, including vehicles, military equipment, aeroplanes, helicopters, rockets, household appliances, and the production of consumer goods, has been on the rise. Additionally, in recent years, composites have become increasingly intertwined with additive technologies, nanotechnologies, biomimetics, and other fields. Beyond creating new composite compositions and structures, as well as technologies for their production at different scales (following a multiscale approach to development), a significant contemporary challenge in science and technology is the production of environmentally friendly composites that can either be recycled or biodegradable /1/. The application of composite materials is exceptionally diverse. They find use in the manufacture of aircraft components, vehicle parts, maritime vessels, energy-related components as solar panels and wind turbines, heating, cooling, and ventilation systems, electrical installations, lighting systems, sanitary devices and fixtures, household appliances, architectural elements in buildings, furniture, sports, and recreational equipment, and more. Different types and technologies of composite materials are continually evolving, aiming to enhance performance and economic efficiency further. Their adoption in modern industry is progressively increasing. Consequently, a structured approach is essential in their development, production, meeting market demands, and ensuring their rational and cost-effective utilization, as well as in the recycling of these materials. Such objectives can only be achieved through the establishment and adherence to standards and standardization.

Briefly about composites

Polymeric materials that have been developed for over a century have the structural ability to enhance their properties through appropriate reinforcement. On the other hand, there are materials with theoretically extremely high strength, such as glass, graphite-carbon, boron, and aramid, but are brittle. By combining materials from these two groups and employing suitable technological procedures for mixing and joining, a synergistic effect on the mechanical properties of the newly created composite material is achieved. These new composed materials are lightweight and high-strength, which is a crucial imperative in the design of modern machines and structures. A composite material comprises a matrix (polymer, metal, ceramic) into which reinforcement (fibres, particles, flakes, and/or fillers) is embedded /2/. The role of the matrix is to maintain the structure's shape, while the reinforcement enhances mechanical properties of the matrix. According to the definition of the concept of composites, the newly combined material should exhibit higher strength and desired properties compared to the individual properties of each material that constitutes the composite, /2/.

Composites are categorized based on the type of matrix they employ, resulting in three primary categories: metal matrix composites (MMC), ceramic matrix composites (CMC), and organic matrix composites (OMC). OMC encompasses polymer matrix composites (PMC) and carbon matrix composites (carbon-carbon composites /2/). Furthermore, composites can be classified according to the type of reinforcement material they utilize. This classification includes fibre reinforcement composites (FRC) which can incorporate either discontinuous (long) or continuous (short) fibres, laminar composites (comprising layers of materials bound together by a matrix, such as sandwich structures), particulate composites (featuring particles as reinforcement, either in flake or powder form), flake composites (employing flat flakes as the reinforcement), and filler composites (utilizing fillers for reinforcement). In FRC structures, small-diameter fibres (typically on the micron scale) are embedded within the matrix material, and composite's properties are influenced by the length of these fibres. Laminar composites are created by assembling layers of materials with the help of a matrix. Particulate composites involve the even distribution of particles throughout the volume of the matrix material, for example, aluminium particles in rubber or silicon carbide particles in aluminium. Filler composites utilize strengthening additives, such as aluminium powder, graphite, calcium carbonate, silicon, or clay. Several technologies are employed in the production of composites, including existing methods used for the production of other structural materials, such as injection moulding /2/. Additionally, there are entirely new technological procedures developed specifically for producing certain composites. The choice of technology depends on several factors, including the matrix material, the binding and strengthening processes, achieving desired properties, constructing composite parts, and subsequent use of finished parts and structures. The fundamental procedure for composite production is moulding, which can take the form of either an open or closed process. One specialized method of composite manufacture is cast polymer moulding. Within these foundational technologies, numerous variations exist, each with its own set of advantages and disadvantages. Some of the commonly employed technologies include /2/: resin transfer moulding (RTM), reaction injection moulding (RIM), structural RIM (SRIM), vacuum-assisted resin transfer moulding (VARTM), compression moulding, injection moulding, filament winding, pultrusion, tube rolling, automated fibre placement (AFP), automated tape laying (ATL), centrifugal casting, and more.

The primary objective when initially developing composite materials was to achieve a combination of key characteristics: individual traits of being lightweight and high-strength, along with a high strength-to-weight ratio. Additionally, over time, these materials have demonstrated various other properties, contingent upon the composition of their components. These include resistance to corrosion, resilience against moisture, water, and chemicals, low thermal conductivity, insulating properties, non-magnetism, radar transparency, and more. Properties of composite materials crucial for engineering design encompass structural adaptability, dimensional stability, and durability. Of particular importance is the fact that modern machine parts can now be manufactured using different composites through additive manufacturing technologies. This integration not only harnesses the inherent qualities of composites but also incorporates the advantages of additive technologies in the contemporary industrial landscape.

STANDARDS AND STANDARDIZATION

A standard is essentially a ‘formula’ that outlines the optimal way to accomplish a task /6/. This task can encompass the supply of materials, the manufacture of various products, process management, service provision, and a wide range of other activities that span a vast spectrum. Academics, researchers, manufacturers, trade associations, vendors, customers, users, regulators, and various other individuals participate either directly or indirectly in the development of standards, /6/. These standards encapsulate knowledge presented in the form of instructions, recommendations, and regulations, all documented in written form for easy distribution in both print and digital formats. Consequently, standards are accessible to all interested parties, serving as a means for people worldwide to better understand one another, act swiftly, and align their actions accordingly. In nearly every facet of life, you'll find at least one standard that plays a pivotal role in the functioning of individuals, diverse communities, various industries, and more. The International Organisation for Standardization (ISO) is an independent, non-governmental international organisation composed of representatives from 168 national standardization bodies worldwide. ISO's mission involves convening experts through its member organisations, who collaborate in specialized committees to share their knowledge and develop international standards. These standards, created through consensus, are market-oriented, foster innovation, and offer solutions to a wide array of contemporary global challenges /6/. ISO has officially existed since 1947 when it had 67 technical committees, each comprising groups of experts dedicated to specific fields and topics. Presently, there are 816 technical committees and subcommittees, responsible for publishing 24,749 standards covering nearly all aspects of technology, management, production, and the utilization of products and services /6/. The majority of these standards pertain to industrial innovation and infrastructure, totalling 13,994 /6/, including those in the field of composite materials. The Technical Committee ISO/TC 61 - Plastics was established in 1947, and within this committee operates the Subcommittee ISO/TC 61/SC 13 - Composites and Reinforcement Fibres, formed in 1985. This subcommittee has published 106 standards, and its experts are presently engaged in developing an additional 15 standards. Various working groups are active within the subcommittee, including WG 1 - Reinforcements and Reinforcement Products, WG 2 - Laminates and Molding Compounds, and WG 7 - Composites and Metal Assemblies. Subcommittee SC 13 comprises representatives from 19 countries, including Belgium (NBN), Brazil (ABNT), China (SAC), Czech Republic (UNMZ), France (AFNOR), Germany (DIN), India (BIS), Italy (UNI), Japan (JISC), the Republic of Korea (KATS), Malaysia (DSM), the Netherlands (NEN), the Russian Federation (GOST), Spain (UNE), Sweden (SIS), Switzerland (SNV), Thailand (TISI), the United Kingdom (BSI), and United States (ANSI). Additionally, eight members hold observer status, including Austria (ASI), Belarus (BELST), Finland (SFS), the Islamic Republic of Iran (INSO), Poland (PKN), Romania (ASRO), South Africa (SABS), and Sri Lanka (SLSI). The International Organisation for Standardization (ISO) is an independent, non-governmental international organisation comprising representatives from 168 national standardization bodies worldwide. ISO facilitates the gathering of experts through its member organisations, who collaborate within appropriate committees to share their knowledge and develop international standards. These standards, created through consensus, are market-oriented, foster innovation, and offer solutions for a wide array of contemporary global challenges /6/. ISO/TC 61/SC 13 is responsible for standards related to composites. Table 1 (published) and Table 2 (under development) provide a comprehensive list of standards under the jurisdiction of ISO/TC 61/SC 13. Table 1 also includes the year of publication for the last edition of each standard. Figure 1 illustrates the evolution of published standards over the years. Despite the subcommittee's establishment in 1985, the first two standards were published in 1990. The majority of standards were released in 2003, with nine standards in total. In 2023, four standards were published, and new editions are expected. Figure 2 displays the distribution of standards across different areas, including fibre reinforcement plastics, textile glass, carbon fibre, reinforcement materials and products, and other - composites, metal assemblies, and reinforcement Fibers. Fibre reinforcement plastics represent the largest category, accounting for nearly half of all standards (43%). Out of the 106 published standards in the field of composites, 26 standards pertain to testing methods. These include standards for producing test plates made of fibre-reinforced plastics (12 standards), tension and compression tests (4 standards), shear tests (2 standards), test methods and test conditions (4 standards), a standard for galvanic corrosion tests, one standard for calibrated end-loaded split (C-ELS) tests, a standard for flexural tests, and a standard for electrochemical tests.

Table 1. Published ISO standards (ISO TC 61/SC 13 - Composites and reinforcement fibres).

No.	Designation	Title	Year
1.	ISO 13002:1998	Carbon fibre - Designation system for filament yarns	1998
2.	ISO 10119:2020	Carbon fibre - Determination of density	2020
3.	ISO 11567:2018	Carbon fibre - Determination of filament diameter and cross-sectional area	2018
4.	ISO 10548:2002	Carbon fibre - Determination of size content	2002
5.	ISO 10548:2002 Cor 1:2008	Carbon fibre - Determination of size content - Technical Corrigendum 1	2002
6.	ISO 10618:2004	Carbon fibre - Determination of tensile properties of resin-impregnated yarn	2004
7.	ISO 11566:1996	Carbon fibre - Determination of the tensile properties of single-filament specimens	1996
8.	ISO 13931:2013	Carbon fibre - Determination of volume resistivity	2013
9.	ISO/TS 23483:2022	Carbon fibres - Determination of polyacrylonitrile-based (PAN-based) carbon fibre tow characteristics - Heat transfer parameter	2022
10.	ISO 22821:2021	Carbon-fibre-reinforced composites - Determination of fibre weight content by thermogravimetry (TG)	2021
11.	ISO 14127:2008	Carbon-fibre-reinforced composites - Determination of the resin, fibre and void contents	2008
12.	ISO 18352:2009	Carbon-fibre-reinforced plastics - Determination of compression-after-impact properties at a specified impact-energy level	2009
13.	ISO 30012:2016	Carbon-fibre-reinforced plastics - Determination of the size and aspect ratio of crushed objects	2016
14.	ISO 30012:2016 Amd 1:2018	Carbon-fibre-reinforced plastics - Determination of the size and aspect ratio of crushed objects - Amendment 1	2016
15.	ISO 15040:1999	Composites - Prepregs - Determination of gel time	1999
16.	ISO 15034:1999	Composites - Prepregs - Determination of resin flow	1999
17.	ISO 21746:2019	Composites and metal assemblies - Galvanic corrosion tests of carbon fibre reinforced plastics (CFRPs) related bonded or fastened structures in artificial atmospheres - Salt spray tests	2019
18.	ISO 24360:2022	Composites and reinforcements fibres - Carbon fibre reinforced plastics (CFRPs) and metal assemblies - Determination of the cross tension strength	2022
19.	ISO 22841:2021	Composites and reinforcements fibres - Carbon fibre reinforced plastics(CFRPs) and metal assemblies - Determination of the tensile lap-shear strength	2021
20.	ISO 22841:2021 Amd 1:2022	Composites and reinforcements fibres - Carbon fibre reinforced plastics(CFRPs) and metal assemblies - Determination of the tensile lap-shear strength - Amendment 1: Precision data	2021
21.	ISO 22838:2020	Composites and reinforcements fibres - Determination of the fracture energy of bonded plates of carbon fibre reinforced plastics (CFRPs) and metal using double cantilever beam specimens	2020
22.	ISO 22836:2020	Fibre-reinforced composites - Method for accelerated moisture absorption and supersaturated conditioning by moisture using sealed pressure vessel	2020
23.	ISO 14130:1997	Fibre-reinforced plastic composites - Determination of apparent interlaminar shear strength by short-beam method	1997
24.	ISO 14130:1997 Cor 1:2003	Fibre-reinforced plastic composites - Determination of apparent interlaminar shear strength by short-beam method - Technical Corrigendum 1	1997
25.	ISO 14126:1999	Fibre-reinforced plastic composites - Determination of compressive properties in the in-plane direction	1999
26.	ISO 14126:1999 Cor 1:2001	Fibre-reinforced plastic composites - Determination of compressive properties in the in-plane direction - Technical Corrigendum 1	1999
27.	ISO 14125:1998	Fibre-reinforced plastic composites - Determination of flexural properties	1998
28.	ISO 14125:1998 Amd 1:2011	Fibre-reinforced plastic composites - Determination of flexural properties - Amendment 1	1998
29.	ISO 12115:1997 Cor 1:1998	Fibre-reinforced plastic composites - Determination of flexural properties - Technical Corrigendum 1	1997
30.	ISO 14125:1998 Cor 1:2001	Fibre-reinforced plastic composites - Determination of flexural properties - Technical Corrigendum 1	1998
31.	ISO 19927:2018	Fibre-reinforced plastic composites - Determination of interlaminar strength and modulus by double beam shear test	2018

32.	ISO 20975-1:2023	Fibre-reinforced plastic composites - Determination of laminate through-thickness properties - Part 1: Direct tension and compression tests	2023
33.	ISO 15024:2023	Fibre-reinforced plastic composites - Determination of mode I interlaminar fracture toughness, GIC, for unidirectionally reinforced materials	2023
34.	ISO 12817:2013	Fibre-reinforced plastic composites - Determination of open-hole compression strength	2013
35.	ISO 12815:2013	Fibre-reinforced plastic composites - Determination of plain-pin bearing strength	2013
36.	ISO 15310:1999	Fibre-reinforced plastic composites - Determination of the in-plane shear modulus by the plate twist method	1999
37.	ISO 14129:1997	Fibre-reinforced plastic composites - Determination of the in-plane shear stress/shear strain response, including the in-plane shear modulus and strength, by the plus or minus 45 degree tension test method	1997
38.	ISO 15114:2014	Fibre-reinforced plastic composites - Determination of the mode II fracture resistance for unidirectionally reinforced materials using the calibrated end-loaded split (C-ELS) test and an effective crack length approach	2014
39.	ISO 23930:2023	Fibre-reinforced plastic composites - Full-section compressive test for pultruded profiles	2023
40.	ISO 20337:2018	Fibre-reinforced plastic composites - Shear test method using a shear frame for the determination of the in-plane shear stress/shear strain response and shear modulus	2018
41.	ISO 20144:2019	Fibre-reinforced plastic composites - Standard qualification plan (SQP) for composite materials, including reduced qualification plan (RQP) and extended qualification plan (EQP) schemes	2019
42.	ISO 20975-2:2018	Fibre-reinforced plastic composites - Determination of laminate through-thickness properties - Part 2: Determination of the elastic modulus, the strength and the Weibull size effects by flexural test of unidirectional laminate, for carbon-fibre based systems	2018
43.	ISO 13003:2003	Fibre-reinforced plastics - Determination of fatigue properties under cyclic loading conditions	2003
44.	ISO 1268-1:2001	Fibre-reinforced plastics - Methods of producing test plates - Part 1: General conditions	2001
45.	ISO 1268-10:2005	Fibre-reinforced plastics - Methods of producing test plates - Part 10: Injection moulding of BMC and other long-fibre moulding compounds - General principles and moulding of multipurpose test specimens	2005
46.	ISO 1268-11:2005	Fibre-reinforced plastics - Methods of producing test plates - Part 11: Injection moulding of BMC and other long-fibre moulding compounds - Small plates	2005
47.	ISO 1268-2:2001	Fibre-reinforced plastics - Methods of producing test plates - Part 2: Contact and spray-up moulding	2001
48.	ISO 1268-3:2000	Fibre-reinforced plastics - Methods of producing test plates - Part 3: Wet compression moulding	2000
49.	ISO 1268-4:2005	Fibre-reinforced plastics - Methods of producing test plates - Part 4: Moulding of prepregs	2005
50.	ISO 1268-4:2005 Amd 1:2010	Fibre-reinforced plastics - Methods of producing test plates - Part 4: Moulding of prepregs - Amendment 1	2005
51.	ISO 1268-5:2001	Fibre-reinforced plastics - Methods of producing test plates - Part 5: Filament winding	2001
52.	ISO 1268-6:2002	Fibre-reinforced plastics - Methods of producing test plates - Part 6: Pultrusion moulding	2002
53.	ISO 1268-7:2001	Fibre-reinforced plastics - Methods of producing test plates - Part 7: Resin transfer moulding	2001
54.	ISO 1268-8:2004	Fibre-reinforced plastics - Methods of producing test plates - Part 8: Compression moulding of SMC and BMC	2004
55.	ISO 1268-9:2003	Fibre-reinforced plastics - Methods of producing test plates - Part 9: Moulding of GMT/STC	2003
56.	ISO 10352:2020	Fibre-reinforced plastics - Moulding compounds and prepregs - Determination of mass per unit area and fibre mass per unit area	2020
57.	ISO 11667:1997	Fibre-reinforced plastics - Moulding compounds and prepregs - Determination of resin, reinforced-fibre and mineral-filler content - Dissolution methods	1997
58.	ISO 12114:1997	Fibre-reinforced plastics - Thermosetting moulding compounds and prepregs - Determination of flowability, maturation and shelf life	1997
59.	ISO 12115:1997	Fibre-reinforced plastics - Thermosetting moulding compounds and prepregs - Determination of flowability, maturation and shelf life	1997
60.	ISO 527-4:2023	Plastics - Determination of tensile properties - Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites	2023
61.	ISO 527-5:2021	Plastics - Determination of tensile properties - Part 5: Test conditions for unidirectional fibre-reinforced plastic composites	2021
62.	ISO 22314:2006	Plastics - Glass-fibre-reinforced products - Determination of fibre length	2006
63.	ISO/TR 13883:1995	Plastics - Guide to the writing of test methods	1995
64.	ISO 8606:1990	Plastics - Prepregs - Bulk moulding compound (BMC) and dough moulding compound (DMC) - Basis for a specification	1990
65.	ISO 9782:1993	Plastics - Reinforced moulding compounds and prepregs - Determination of apparent volatile-matter content	1993
66.	ISO 15100:2000	Plastics - Reinforcement fibres - Chopped strands - Determination of bulk density	2000
67.	ISO 17771:2003	Plastics - Thermoset moulding compounds - Determination of the degree of fibre wetting in SMC	2003
68.	ISO 4604:2011	Reinforcement fabrics - Determination of conventional flexural stiffness - Fixed-angle flexometer method	2011
69.	ISO 2113:1996	Reinforcement fibres - Woven fabrics - Basis for a specification	1996
70.	ISO 2113:1996 Cor 1:2003	Reinforcement fibres - Woven fabrics - Basis for a specification - Technical Corrigendum 1	1996
71.	ISO 10371:1993	Reinforcement materials - Braided tapes - Basis for a specification	1993
72.	ISO 10122:2014	Reinforcement materials - Tubular braided sleeves - Basis for a specification	2014
73.	ISO 3344:1997	Reinforcement products - Determination of moisture content	1997
74.	ISO 3374:2000	Reinforcement products - Mats and fabrics - Determination of mass per unit area	2000

75.	ISO 5025:2017	Reinforcement products - Woven fabrics - Determination of width and length	2017
76.	ISO 1889:2009	Reinforcement yarns - Determination of linear density	2009
77.	ISO 1890:2009	Reinforcement yarns - Determination of twist	2009
78.	ISO 3343:2010	Reinforcement yarns - Determination of twist balance index	2010
79.	ISO 4602:2010	Reinforcements - Woven fabrics - Determination of number of yarns per unit length of warp and weft	2010
80.	ISO 3616:2022	Textile glass - Chopped-strand and continuous-filament mats - Determination of average thickness, thickness under load and recovery after compression	2022
81.	ISO 1887:2014	Textile glass - Determination of combustible-matter content	2014
82.	ISO 3375:2009	Textile glass - Determination of stiffness of rovings	2009
83.	ISO 3342:2011	Textile glass - Mats - Determination of tensile breaking force	2011
84.	ISO 2559:2011	Textile glass - Mats (made from chopped or continuous strands) - Designation and basis for specifications	2011
85.	ISO 4900:2011	Textile glass - Mats and fabrics - Determination of contact mouldability	2011
86.	ISO 2797:2017	Textile glass - Rovings - Basis for a specification	2017
87.	ISO 9163:2005	Textile glass - Rovings - Manufacture of test specimens and determination of tensile strength of impregnated rovings	2005
88.	ISO 1888:2022	Textile glass - Staple fibres or filaments - Determination of average diameter	2022
89.	ISO 8516:2011	Textile glass - Textured yarns - Basis for a specification	2011
90.	ISO 4606:1995	Textile glass - Woven fabric - Determination of tensile breaking force and elongation at break by the strip method	1995
91.	ISO 4603:1993	Textile glass - Woven fabrics - Determination of thickness	1993
92.	ISO 4603:1993 Amd 1:2010	Textile glass - Woven fabrics - Determination of thickness - Amendment 1	1993
93.	ISO 3598:2011	Textile glass - Yarns - Basis for a specification	2011
94.	ISO 2078:2022	Textile glass - Yarns - Designation	2022
95.	ISO 3341:2000	Textile glass - Yarns - Determination of breaking force and breaking elongation	2000
96.	ISO 2558:2010	Textile glass chopped-strand mats for reinforcement of plastics - Determination of time of dissolution of the binder in styrene	2010
97.	ISO 7822:1990	Textile glass reinforced plastics - Determination of void content - Loss on ignition, mechanical disintegration and statistical counting methods	1990
98.	ISO 15039:2003	Textile-glass rovings - Determination of solubility of size	2003
99.	ISO 15039:2003 Amd 1:2015	Textile-glass rovings - Determination of solubility of size - Amendment 1	2003
100.	ISO 3597-1:2003	Textile-glass-reinforced plastics - Determination of mechanical properties on rods made of roving-reinforced resin - Part 1: General considerations and preparation of rods	2003
101.	ISO 3597-2:2003	Textile-glass-reinforced plastics - Determination of mechanical properties on rods made of roving-reinforced resin - Part 2: Determination of flexural strength	2003
102.	ISO 3597-3:2003	Textile-glass-reinforced plastics - Determination of mechanical properties on rods made of roving-reinforced resin - Part 3: Determination of compressive strength	2003
103.	ISO 3597-4:2003	Textile-glass-reinforced plastics - Determination of mechanical properties on rods made of roving-reinforced resin - Part 4: Determination of apparent interlaminar shear strength	2003
104.	ISO 1172:1996	Textile-glass-reinforced plastics - Prepregs, moulding compounds and laminates - Determination of the textile-glass and mineral-filler content - Calcination methods	1996
105.	ISO 8605:2001	Textile-glass-reinforced plastics - Sheet moulding compound (SMC) - Basis for a specification	2001
106.	ISO 4899:1993	Textile-glass-reinforced thermosetting plastics - Properties and test methods	1993

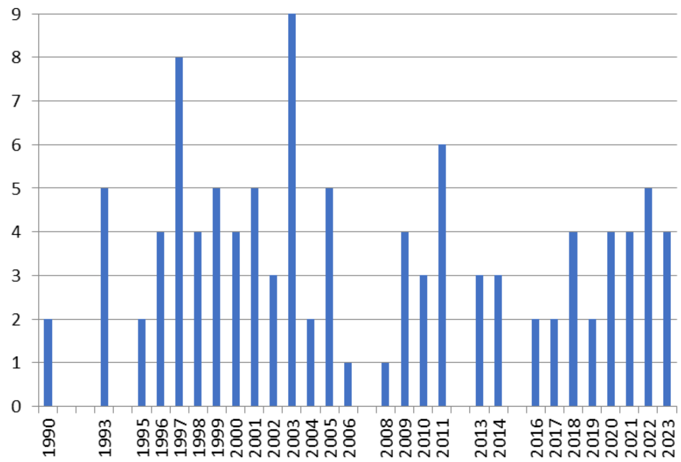

Figure 1. Number of published ISO standards over the years.

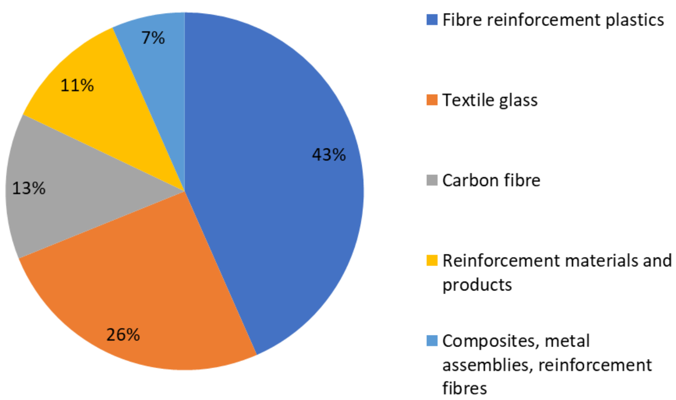

Figure 2. Percentage of published ISO standards by field.

Table 2. ISO standards under development (ISO TC 61/SC 13).

No.	Designation	Title
	ISO/DIS 14127	Carbon-fibre-reinforced composites - Determination of the resin, fibre and void contents
	ISO/DIS 8060	Composites and reinforcements fibres - Carbon fibre reinforced plastics (CFRPs) and metal assemblies - Characterization of durability of adhesive interfaces by wedge rupture test
	ISO/DIS 8065	Composites and reinforcements fibres - Mechanoluminescent visualization method of crack propagation for joint evaluation
	ISO/DIS 8057	Determination of galvanic corrosion rate for assembled forms of carbon fibre reinforced plastics (CFRPs) and protection-coated metal - Electrochemical tests in neutral sodium chloride solution
	ISO/DIS 4410	Experimental characterization of in-plane permeability of fibrous reinforcements for liquid composite moulding
	ISO/DIS 14126	Fibre-reinforced plastic composites - Determination of compressive properties in the in-plane direction
	ISO/WD 8203-2	Fibre-reinforced plastics - Non-destructive inspection techniques - Part 2: Ultrasonic - Phased array and air coupled
	ISO/WD 8203-3	Fibre-reinforced plastics - Non-destructive inspection techniques - Part 3: Thermographic techniques
	ISO/WD 8203-4	Fibre-reinforced plastics - Non-destructive inspection techniques - Part 4: Laser shearography
	ISO/WD 8203-5	Fibre-reinforced plastics - Non-destructive inspection techniques - Part 5: Microwave
	ISO/DIS 8605	Fibre-reinforced plastics - Sheet moulding compound (SMC) - Basis for a specification
	ISO/DIS 23927	Laminates and moulding compounds - Prepregs - Determination of tack
	ISO/DIS 22314	Plastics - Glass-fibre-reinforced products - Determination of fibre length
	ISO/PRF 2113	Reinforcement fibres - Woven fabrics - Requirements and specifications
	ISO/DIS 1172	Textile-glass-reinforced plastics - Prepregs, moulding compounds and laminates - Determination of the textile-glass and mineral-filler content - Calcination methods

ASTM International, also known as the American Society for Testing and Materials, is a global standardization organisation dedicated to the development and publication of international standards in various fields, including materials, products, systems, and services. Founded in 1902, ASTM International established official cooperation with the European Committee for Standardization (CEN) in 2019 through the signing of a Technical Cooperation Agreement, which was extended and expanded in 2022. ASTM International produces six types of standards: test methods, specifications, classifications, practices, guides, and terminology. The organisation comprises over 140 committees responsible for issuing more than 12,800 global standards /7/. Among these committees, the D30 Committee for Composite Materials was established in 1964. With a membership of 250 individuals representing an international community of composite materials enthusiasts, this committee was created to serve the aerospace industry but has since broadened its support to industries including automotive, industrial, sports, and medical products utilizing advanced composite materials. Committee D30 focuses on developing standard terminology, guidelines, test methods, and practical applications for composite materials, primarily those reinforced with fibres boasting Young's modulus exceeding 20 GPa /8/. The standards under the purview of ASTM Technical Committee D30 are listed in Table 3, categorized by subcommittee. Notably, some subcommittees have yet to publish standards. Table 3 also provides information on the publication years of the latest editions of referenced standards. Figure 3 illustrates the number of standards published over the years by Committee D30, totalling 97 standards. The earliest edition dates back to 2015, with a significant uptick in new publications and updates starting from 2018, especially in the field of composites. The year 2022 saw the highest number of editions released (25 standards), and further standards can be expected in 2023. Figure 4 displays the distribution of standards across subcommittees within Committee D30.

Table 3. Published ASTM standards (TC D30), in total 97 standards.

SC	SC name	Standard designation	Title	Year
D30.01	Editorial and Resource Stand.	D3878-20b	Standard Terminology for Composite Materials	2020
		D4762-18	Standard Guide for Testing Polymer Matrix Composite Materials	2018
		D6507-19	Standard Practice for Fiber Reinforcement Orientation Codes for Composite Materials	2019
		D8335-20	Standard Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials	2020
D30.03	Constituent/Precursor Properties	C613-19	Standard Test Method for Constituent Content of Composite Prepreg by Soxhlet Extraction	2019
		D3529-16 (2021)	Standard Test Methods for Constituent Content of Composite Prepreg	2021
		D3530-20	Standard Test Method for Volatiles Content of Composite Material Prepreg	2020
		D3531/D3531M-16	Standard Test Method for Resin Flow of Carbon Fiber-Epoxy Prepreg	2016
		D3532/D3532M-19	Standard Test Method for Gel Time of Carbon Fiber-Epoxy Prepreg	2019
		D3800-22	Standard Test Method for Density of High-Modulus Fibers	2022
		D4018-17	Standard Test Methods for Properties of Continuous Filament Carbon and Graphite Fiber Tows	2017
		D4102/D4102M-22	Standard Test Method for Thermal Oxidative Resistance of Carbon Fibers	2022
		D7750-12 (2017)	Standard Test Method for Cure Behavior of Thermosetting Resins by Dynamic Mechanical Procedures using an Encapsulated Specimen Rheometer	2017
		D8132/D8132M-17	Standard Test Method for Determination of Prepreg Impregnation by Permeability Measurement	2017
		D8336-21	Standard Test Method for Characterizing Tack of Prepregs Using a Continuous Application-and-Peel Procedure	2021

D30.04 Lamina and Laminate Test Methods	D2344/D2344M-22	Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates	2022
	D3039/D3039M-17	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials	2017
	D3171-22	Standard Test Methods for Constituent Content of Composite Materials	2022
	D3410/D3410M-16e1	Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading	2021
	D3479/D3479M-19	Standard Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials	2019
	D3518/D3518M-18	Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate	2018
	D3552-17	Standard Test Method for Tensile Properties of Fiber Reinforced Metal Matrix Composites	2017
	D4255/D4255M-20e1	Standard Test Method for In-Plane Shear Properties of Polymer Matrix Composite Materials by the Rail Shear Method	2023
	D5229/D5229M-20	Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials	2020
	D5379/D5379M-19e1	Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method	2021
	D5448/D5448M-22	Standard Test Method for Inplane Shear Properties of Hoop Wound Polymer Matrix Composite Cylinders	2022
	D5449/D5449M-22	Standard Test Method for Transverse Compressive Properties of Hoop Wound Polymer Matrix Composite Cylinders	2022
	D5450/D5450M-22	Standard Test Method for Transverse Tensile Properties of Hoop Wound Polymer Matrix Composite Cylinders	2022
	D5467/D5467M-97 (2017)	Standard Test Method for Compressive Properties of Unidirectional Polymer Matrix Composite Materials Using a Sandwich Beam	2017
	D5687/D5687M-20	Standard Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation	2020
	D6641/D6641M-16e2	Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture	2021
	D6856/D6856M-03 (2016)	Standard Guide for Testing Fabric-Reinforced “Textile” Composite Materials	2016
	D7028-07 (2015)	Standard Test Method for Glass Transition Temperature (DMA Tg) of Polymer Matrix Composites by Dynamic Mechanical Analysis (DMA)	2015
	D7078/D7078M-20e1	Standard Test Method for Shear Properties of Composite Materials by V-Notched Rail Shear Method	2021
	D7264/D7264M-21	Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials	2021
D30.05 Structural Test Methods	D5766/D5766M-11 (2018)	Standard Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates	2018
	D5961/D5961M-17	Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates	2017
	D6264/D6264M-17	Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Concentrated Quasi-Static Indentation Force	2017
	D6484/D6484M-20	Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates	2020
	D6742/D6742M-17	Standard Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates	2017
	D6873/D6873M-19	Standard Practice for Bearing Fatigue Response of Polymer Matrix Composite Laminates	2019
	D7136/D7136M-20	Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event	2020
	D7137/D7137M-17	Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates	2017
	D7248/D7248M-21	Standard Test Method for High Bearing – Low Bypass Interaction Response of Polymer Matrix Composite Laminates Using 2-Fastener Specimens	2021
	D7332/D7332M-22	Standard Test Method for Measuring the Fastener Pull-Through Resistance of a Fiber-Reinforced Polymer Matrix Composite	2022
	D7615/D7615M-19	Standard Practice for Open-Hole Fatigue Response of Polymer Matrix Composite Laminates	2019
	D8066/D8066M-17	Standard Practice Unnotched Compression Testing of Polymer Matrix Composite Laminates	2017
	D8101/D8101M-18	Standard Test Method for Measuring the Penetration Resistance of Composite Materials to Impact by a Blunt Projectile	2018
	D8131/D8131M-17e1	Standard Practice for Tensile Properties of Tapered and Stepped Joints of Polymer Matrix Composite Laminates	2017
	D8387/D8387M-21	Standard Test Method for High Bypass – Low Bearing Interaction Response of Polymer Matrix Composite Laminates	2021
	E1922/E1922M-22	Standard Test Method for Translaminar Fracture Toughness of Laminated and Pultruded Polymer Matrix Composite Materials	2022
D30.06 Inter-laminar Properties	D5528/D5528M-21	Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites	2021
	D6115-97(2019)	Standard Test Method for Mode I Fatigue Delamination Growth Onset of Unidirectional Fiber-Reinforced Polymer Matrix Composites	2019

	D6415/D6415M-22	Standard Test Method for Measuring the Curved Beam Strength of a Fiber-Reinforced Polymer-Matrix Composite	2022
	D6671/D6671M-22	Standard Test Method for Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites	2022
	D7291/D7291M-22	Standard Test Method for Through-Thickness “Flatwise” Tensile Strength and Elastic Modulus of a Fiber-Reinforced Polymer Matrix Composite Material	2022
	D7905/D7905M-19e1	Standard Test Method for Determination of the Mode II Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites	2019
D30.09 Sandwich Construction	C271/C271M-16 (2022)e1	Standard Test Method for Density of Sandwich Core Materials	2022
	C272/C272M-18	Standard Test Method for Water Absorption of Core Materials for Sandwich Constructions	2018
	C273/C273M-20	Standard Test Method for Shear Properties of Sandwich Core Materials	2020
	C297/C297M-16	Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions	2016
	C363/C363M-16	Standard Test Method for Node Tensile Strength of Honeycomb Core Materials	2016
	C364/C364M-16	Standard Test Method for Edgewise Compressive Strength of Sandwich Constructions	2016
	C365/C365M-22	Standard Test Method for Flatwise Compressive Properties of Sandwich Cores	2022
	C366/C366M-16 (2022)e1	Standard Test Methods for Measurement of Thickness of Sandwich Cores	2022
	C393/C393M-20	Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure	2020
	C394/C394M-16	Standard Test Method for Shear Fatigue of Sandwich Core Materials	2016
	C480/C480M-16	Standard Test Method for Flexure Creep of Sandwich Constructions	2016
	C481-99(2016)	Standard Test Method for Laboratory Aging of Sandwich Constructions	2016
	D6416/D6416M-16e1	Standard Test Method for Two-Dimensional Flexural Properties of Simply Supported Sandwich Composite Plates Subjected to a Distributed Load	2021
	D6772/D6772M-22	Standard Test Method for Dimensional Stability of Sandwich Core Materials	2022
	D6790/D6790M-22	Standard Test Method for Determining Poisson‘s Ratio of Honeycomb Cores	2022
	D7249/D7249M-20	Standard Test Method for Facesheet Properties of Sandwich Constructions by Long Beam Flexure	2020
	D7250/D7250M-20	Standard Practice for Determining Sandwich Beam Flexural and Shear Stiffness	2020
	D7336/D7336M-22	Standard Test Method for Static Energy Absorption Properties of Honeycomb Sandwich Core Materials	2022
	D7766/D7766M-16	Standard Practice for Damage Resistance Testing of Sandwich Constructions	2016
	D7956/D7956M-16	Standard Practice for Compressive Testing of Thin Damaged Laminates Using a Sandwich Long Beam Flexure Specimen	2016
	D8067/D8067M-17	Standard Test Method for In-Plane Shear Properties of Sandwich Panels Using a Picture Frame Fixture	2017
	D8285/D8285M-19	Standard Practice for Compressive Properties of Tapered and Stepped Joints of Polymer Matrix Composite Laminates by Sandwich Construction Long Beam Flexure	2019
	D8287/D8287M-22	Standard Test Method for Compressive Residual Strength Properties of Damaged Sandwich Composite Panels	2022
	D8388/D8388M-22	Standard Practice for Flexural Residual Strength Testing of Damaged Sandwich Constructions	2022
	D8453/D8453M-22	Standard Practice for Open-Hole Flexural Strength of Sandwich Constructions	2022
	D8454/D8454M-22	Standard Test Method for Open-Hole Compressive Strength of Sandwich Constructions	2022
	F1645/F1645M-22	Standard Test Method for Water Migration in Honeycomb Core Materials	2022
D30.10 Composites for Civil Structures	D7205/D7205M-21	Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars	2021
	D7290-06 (2022)	Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications	2022
	D7337/D7337M-12 (2019)	Standard Test Method for Tensile Creep Rupture of Fiber Reinforced Polymer Matrix Composite Bars	2019
	D7522/D7522M-21	Standard Test Method for Pull-Off Strength for FRP Laminate Systems Bonded to Concrete or Masonry Substrates	2021
	D7565/D7565M-10 (2017)	Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures	2017
	D7616/D7616M-11 (2023)	Standard Test Method for Determining Apparent Overlap Splice Shear Strength Properties of Wet Lay-Up Fiber-Reinforced Polymer Matrix Composites Used for Strengthening Civil Structures	2023
	D7617/D7617M-11 (2017)	Standard Test Method for Transverse Shear Strength of Fiber-reinforced Polymer Matrix Composite Bars	2017
	D7705/D7705M-12 (2019)	Standard Test Method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction	2019
	D7913/D7913M-14 (2020)	Standard Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing	2020
	D7914/D7914M-21	Standard Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations	2021

D7957/D7957M-22	Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement	2022
D7958/D7958M-17	Standard Test Method for Evaluation of Performance for FRP Composite Bonded to Concrete Substrate using Beam Test	2017
D8337/D8337M-21	Standard Test Method for Evaluation of Bond Properties of FRP Composite Applied to Concrete Substrate using Single-Lap Shear Test	2021

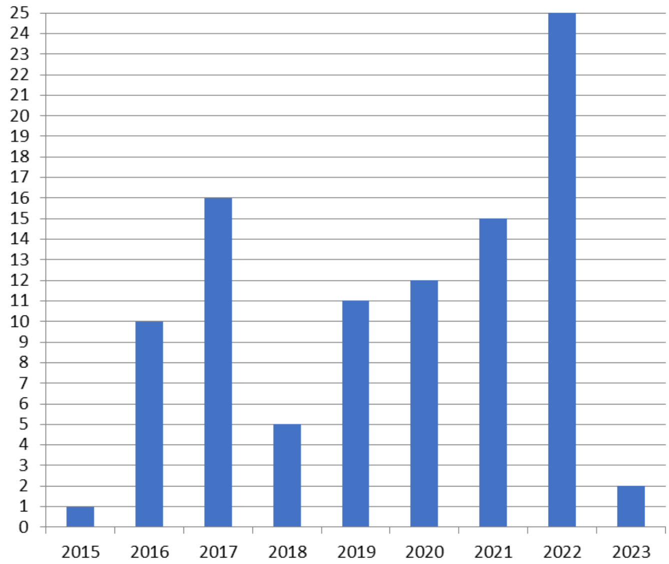

Figure 3. Number of published ASTM standards over the years.

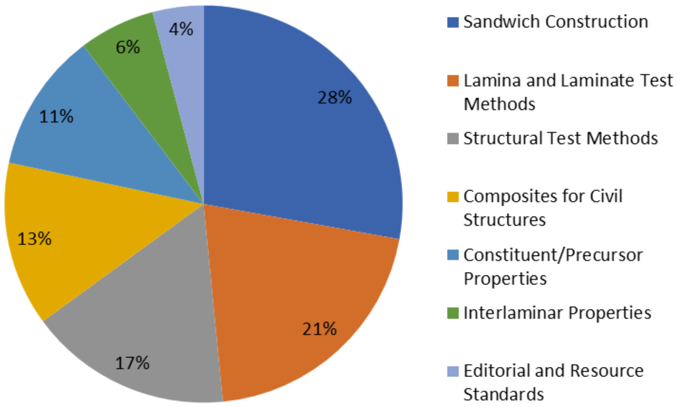

Figure 4. Percentage of published ASTM standards by subcommittee.

CONCLUSIONS

The paper provides a comprehensive overview of the current state of standardization in the field of composite materials. The need for standardization in the composite materials industry has become increasingly evident as their applications have expanded. Data presented in this paper, including tables and figures, offer valuable insights into the quantity and distribution of standards. Furthermore, continuous growth in the number of standards published over the years is highlighted, indicating the dynamic nature of composite materials research and development. As composite materials continue to evolve and find new applications, it is expected that standardization efforts will remain essential to meet the growing demands of industry and to address emerging challenges, such as sustainability and recyclability. Based on the conducted analyses, the following conclusions are drawn:

- Within organisations that publish international standards such as ISO and ASTM International, committees and subcommittees focused on standards and standardization in the field of composite materials have been active for nearly 40 years.
- Since 1990, ISO has released 106 standards, with additional 15 currently in development.
- Since 2015, ASTM International has published 97 standards.
- Despite the substantial number of existing standards, the need for more standards remains evident. New technologies are continuously emerging, and there are evolving requirements driven by digital industries, modern society, environmental considerations, recycling, biodegradability, and environmental protection.
- A comparison between ISO and ASTM International standards reveals similarities, overlaps, and differences. These two organisations complement each other with their respective standards; when an ISO standard is unavailable, an ASTM standard can be applied, and vice versa.
- Expectations point to further robust development in standards for the production and utilization of composite materials.

ACKNOWLEDGEMENT

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