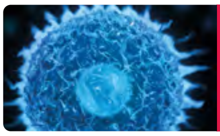

ADVANCED MATERIALS SCIENCE

Fields of Expertise TU Graz

Source: istockphoto.com

Christof Sommitsch, Advanced Materials Science
Source: Lunghammer – TU Graz

Sustainable construction and building requires smart materials with specific properties such as light weight, optimized heat conductivity and capacity, and corrosion resistance, among others. Today's challenges are intelligent surfaces, compound design and the integration of sensors and functional devices such as for heating and cooling, energy harvesting and translucence.

In the 16th call of the initial seed funding of TU Graz, we are happy to finance four interesting and challenging applications in chemistry and physics. The awardees are Markus Koch (Institute of Experimental Physics) with the topic "Ultrafast microscopy to optimize materials for sustainable energy production", Christa Grogger (Institute of Inorganic Chemistry) with her application on "Disilacyclohexadienes as precursors to electronically active materials", Roland Fischer (Institute of Inorganic Chemistry) with research on "Bismuth for REDuctive chemical EnergY conversion", and Bernhard Gollas (Institute of Chemical Technologies of Materials) applying for "Redox-flow battery with eco-friendly electrolyte from renewable sources". We are looking forward to extraordinary results and future projects.

On January 26th in 2022, we organized the subsequent FoE AMS online update. After the general update by the FoE leadership, there were two very interesting talks. Florian Feist, senior scientist at the Vehicle Safety Institute gave an overview on the EU-project BreadCell, and Qabar Abbas, visiting researcher at the Institute for Chemistry and Technology of Materials talked about hybrid-supercapacitors made from environmentally friendly components.

The Advanced Materials Poster Day took place on 22nd April, 2022, with invited talks as well as a poster show and advanced discussion.

As a contribution to this issue, Sergio Amancio, holder of the BMK Endowed Professorship for Aviation from the Institute of Materials Science, Joining and Forming gives an overview about his research area aviation materials and manufacturing techniques in general, and on ongoing projects relating to the joining of additive manufactured metallic and polymeric parts for mobility applications in particular.

Sergio Amancio

Aviation Materials and Manufacturing Techniques

Commercial flights produced about 915 million tonnes of CO_2 worldwide in 2019 [1]. In reaction to this critical situation the European Commission (EC) has recently set the goal of achieving climate neutrality by 2050 [2], which is also an obligation for Austria. One way of accomplishing this target involves the development of greener (e.g. hybrid-electric aircrafts, fuel cell powering electric motors) propulsion systems in lighter and more sustainable aircraft.

The BMK Endowed Professorship for Aviation (B-EPA) is located at TU Graz in the Institute of Materials Science, Joining and Forming (IMAT). B-EPA is co-financed by the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK), and the Austrian companies Diamond Aircraft, voestalpine, TCM International and Fuchshofer. The team led by Sergio Amancio has set >

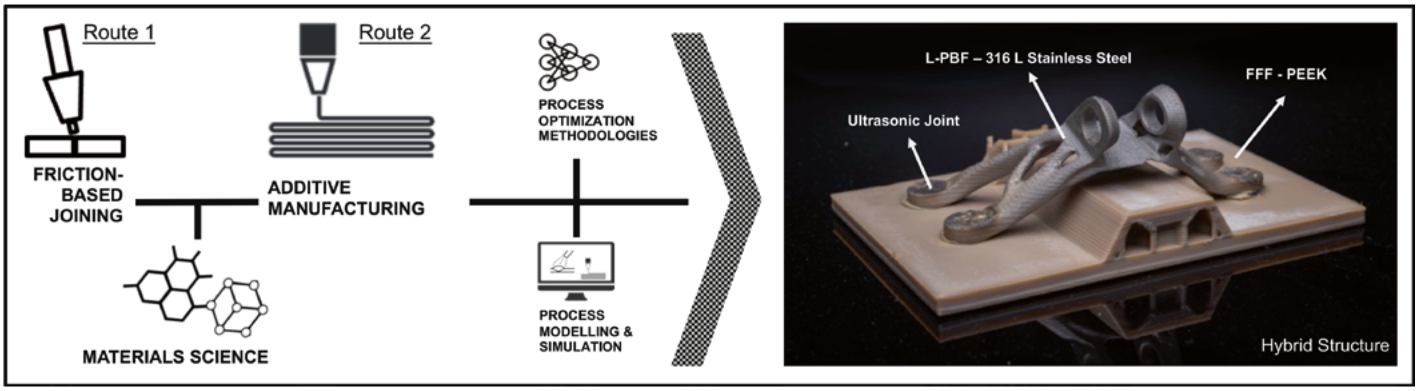

Figure 1: Graphical description of the aviation team's scientific-engineering approach.

Source: Willian Carvalho, Christian Hoflehner, Sergio Amancio

the goal of developing innovative and novel engineering approaches to produce light-weight and high-performance lightweight metals, composites, and metal-composite hybrid structures. The focus of the team is on sustainable materials with improved recyclability to support the circular economy. Examples of these are carbon and glass-fiber reinforced thermoplastic composites – a class of recyclable and repairable composite materials – which may be combined with lightweight and high strength alloys, for instance aluminum, titanium and stainless steel, to reduce aircraft weight without compromising passenger safety.

The manufacturing of metal-composite hybrid structures presents great challenges, due to their incompatibility in physico-chemical material properties. B-EPA's R&D approach has the goal of mitigating these challenges by combining materials science knowledge, joining and additive manufacturing (AM) processes to produce metal-thermoplastic composites hybrid structures (MTC-HS). These hybrid structures have high strength-to-weight performance, improved damage tolerance and crash-worthiness. Moreover, MTC-HS have good repairability (e.g. by thermal joining or welding) and are easily disassembled and recycled since their thermoplastic composite matrix can be remelted; therefore, thermoplastic composite matrix can be returned to the material cycle.

COMBINING JOINING, ADDITIVE MANUFACTURING AND MATERIALS SCIENCE – A UNIQUE SCIENTIFIC-ENGINEERING APPROACH

The R&D methodology at B-EPA combines materials science knowledge, advanced friction-based joining and new additive manufacturing routes, which are supported by process optimization, modelling and simulation tools. Our scientific-engineering approach is schematically presented in Figure 1. In this methodology innovative friction-based joining techniques are combined with additive manufacturing of metals (powder bed and directed energy deposition processes) and engineering thermoplastics composites (e.g. via FFF/FDM) to produce MTC-HS.

Two innovative manufacturing routes to produce MTC-HS have been followed at B-EPA:

1. Friction-based joining (FB-J) and 2. additive manufacturing (AM). In the friction-based joining method both the metal and polymer/composite parts are produced separately, whereby formative, subtractive or additive manufacturing can be used for this purpose. A FB-J technique is subsequently utilized to join the MC-HS. In the AM method, the metal part is preferentially produced by AM processes (state-of-the-art metal manufacturing processes may be also applied) and is subsequently hybridized by by polymer/composite 3D printing. Process optimization methodologies, such as design of experiments (DoE) and analysis of variance (ANOVA), as well as machine learning (e.g. through supervised learning regression) are combined with process modelling and simulation (i.e., FEA, CFD, Topology Optimization) to understand and optimize the manufacturing processes and properties of MC-HS.

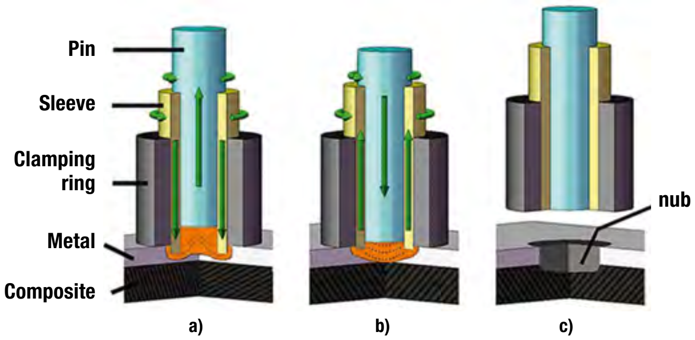

Figure 2:
Schematics of the friction spot joining (FSpJ) technique.
(a) The sleeve plunging softens the metal alloy and melts the composite by thermal conduction over the interface;
(b) spot refilling ("key-hole refilling"); (c) joint consolidation.

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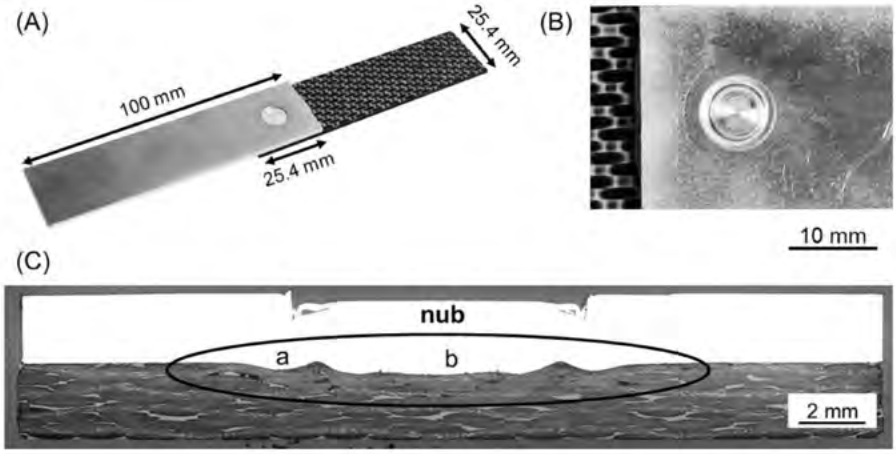

Figure 3:
(A) Example of an AA7075-T6/CF-PPS friction spot joint along with typical (B) top view and (C) cross-section of the joints. The metallic nub is indicated with an ellipse in (C).
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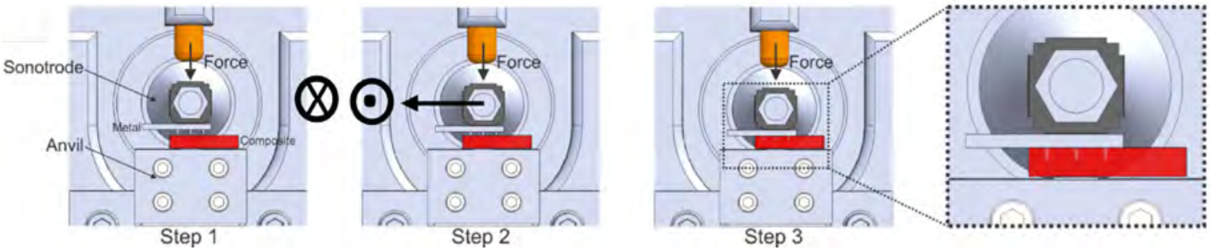

Figure 4: Schematics of the U-joining technique. Step 1: The surfaces of the integrated pins are set into contact with the upper surface of the polymer/ composite; Step 2: The sonotrode starts to vibrate and the tool applies vertical pressure against the parts, generating frictional heat at the interface between the pins and the polymer/composite. Consequently, the polymer below these contact points melts or softens (depending on its type), and the pins start to penetrate the thermoplastic; Step 3 shows the consolidation phase.
Figure: Willian Carvalho, 2021.

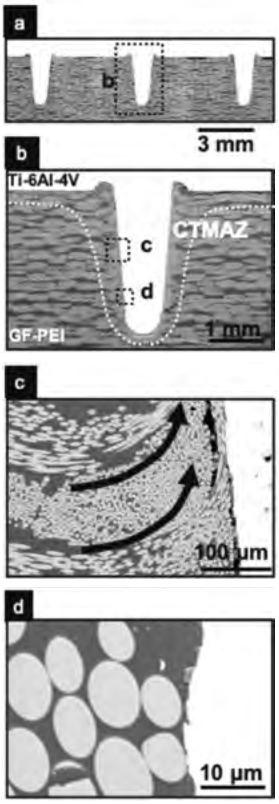

Figure 5: Example of the microstructure of ultrasonically joined glass-fiber reinforced polyetherimide (GF-PEI) with Ti-6Al-4V metallic connector with integrated conical pins. (a) Overview of joint cross section; (b) Detail of the composite thermo-mechanically affected zone (CTMAZ); (c) and (d) are detail photos of regions marked in (b), showing the interface between integrated pins and composite .
Photos: E. Feistauer, 2018

FRICTION-BASED JOINING PROCESSES

Joining of hybrid metal-polymer and polymer composite structures is a hot topic that will be extensively addressed in the coming decades. Although encouraging, the transition from similar to hybrid lightweight structures usually requires new joining concepts, since the traditional welding and joining techniques are not directly transferrable to such material combinations. This is mostly due to their physical and chemical material dissimilarities, which hinder miscibility during the joining of materials. FB-J processes for MTC-HS are well known to be highly energy efficient converting usually over 90% of the input electric energy into frictional heat for the joining procedure. In comparison to laser joining with 30%-70% energy efficiency, FB-J process can be considered greener manufacturing processes. The FB-J processes for MTC-HS use rotation (or ultrasonic vibration) and pressure to create heat by friction, plastically deforming the metal component to induce geometrical interlocking with the polymer; concomitantly the polymeric part is soften or molten by heat transfer from the metal. A combination of macro or micro-mechanical interlocking together with strong adhesion forces are thus typically present in the FB-joined MTC-HS. Due to the lower process temperatures and short joining cycles (a few seconds only instead of many minutes or hours observed in actual mechanical fastening and adhesive bonding) the polymeric composite matrix is not decomposed and keeps its structural integrity. Furthermore, the fiber reinforcement of composite part is only slightly disturbed or slightly damaged, whereby original polymer composite properties are kept virtually intact. No pre-drilling of through-holes are required in the parts, which reduces stresses in the composite. A friction-based joined MTC-HS displaying high quasi-static, dynamic and impact loading

Figure 6: Schematic representation of friction riveting process steps for an overlap joint between two polymer plates: a) positioning of the joining parts, b) friction phase (plunging of the rotating rivet through the upper part), c) forging phase (plunging of the rivet through the lower part and rivet plastic deformation), and d) joint consolidation. The polymeric flash formed during the process was not illustrated for simplification.

Figure: Natascha Zocoller, 2020).

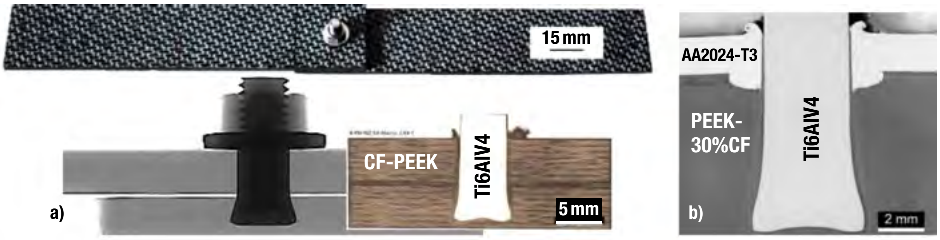

Figure 7: Examples of the microstructure of two friction-riveted joints: (a) a single-lap joint of CF-PEEK joined with Ti6Al4V rivets; (b) a single-lap joint between aluminium 2024-T3 and PEEK reinforced with 30% short-carbon fibers joined by Ti6Al4V rivets.

Figure: Natascha Zocoller, 2020

strength, damage tolerance, and durability (i.e. resistance to natural and artificial ageing) can be thus achieved in a simpler, faster and environmentally friendly way without emissions or chemical disposals. Moreover, the reconsolidated polymer at the metal-composite interface creates a barrier to the development of corrosion, which is a frequent issue related to the galvanic coupling between metal and carbon fiber reinforced composites.

Sergio Amancio is deputy head of the Institute of Materials Science, Joining and Forming and holder of the BMK Endowed Professorship for Aviation. He studied Materials Engineering with a specialization in Polymers and Metallurgy at UFSCar, Brazil. During his PhD at the Hamburg University of Technology, and post-doctoral studies at Helmholtz-Zentrum Geesthacht, he developed and patented new joining and additive manufacturing techniques for metal-composite hybrid structures.

Source: Lunghammer – TU Graz

Three novel friction-based joining technologies patented by Amancio's team [3], are being investigated and further developed at TU Graz: friction spot joining (FSpJ) [4], ultrasonic joining (U-Joining) [5] and friction riveting (FricRiveting) [6]. These techniques are complimentary to each other finding specific application niches for different materials thicknesses and structural applications. Figures 2 to 7 show the schematics of the processes and the microstructural characteristics of typical hybrid joints.

NEW ADDITIVE MANUFACTURING ROUTES

The manufacture of engineering metal-polymer layered parts is currently a highly demanding Procedure. Long processing cycles are usually required to cure the thermoset-based resin composites and the use of expensive molds, such as in the fabrication of epoxy-based fiber-metal laminates (FML) is absolutely essential. Thermoplastic-based FML (T-FML), such as carbon-fiber reinforced PEEK/Ti can be produced with shorter thermoforming cycles. However, there are challenges on the automation and ability to make complex T-FML 3D-parts. Lately, an increased interest in the field of AM promotes the flexibility of producing complex 3D-parts with net-shape and mechanical functionalities, e.g. sandwich-structures with AM honeycomb cores.

AddJoining [7] is a novel method to produce layered MTC-HS based on the principles of joining and the polymeric AM. AddJoining uses fused filament fabrication (FFF) to hybridize metals – i.e. to form the polymeric/composite part around the metal parts. Hence, the parts can be produced with complex 3D-geometries by depositing extruded material layer by layer on a metallic substrate (e.g. in extruded, rolled, machined or additively manufactured metals). AddJoining is presented in Figure 8. The manufacturing times for AddJoining are in the scale of minutes in comparison to the typical several hours in state-of-the-art composite lamination processes. No molds are required and robotic application is possible. Figure 9 shows examples of two different metal-composite Add-joints. Figure 10 shows examples of additively manufactured and joined MTC-HS produced at TU Graz.

Sergio Amancio and collaborators gratefully acknowledge financial support from the Austrian aviation program "TAKE-OFF" and from the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK). Part of the work in this article was co-financed by National Council for Scientific and Technological Development – CNPq (Brazil).

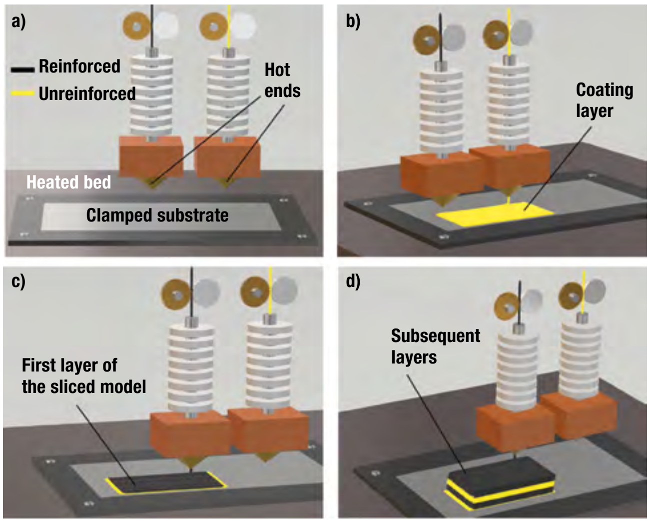

Figure 8: Schematic representation of the AddJoining process for layered metal-thermoplastic composite hybrid structures: (a) initial setup, (b) deposition of the first polymer layer – the coating layer – on the metal substrate, (c) deposition of the subsequent polymer layers, (d) final layered metal-polymer/ composite hybrid structure.

Figure: Carlos Belei, 2021

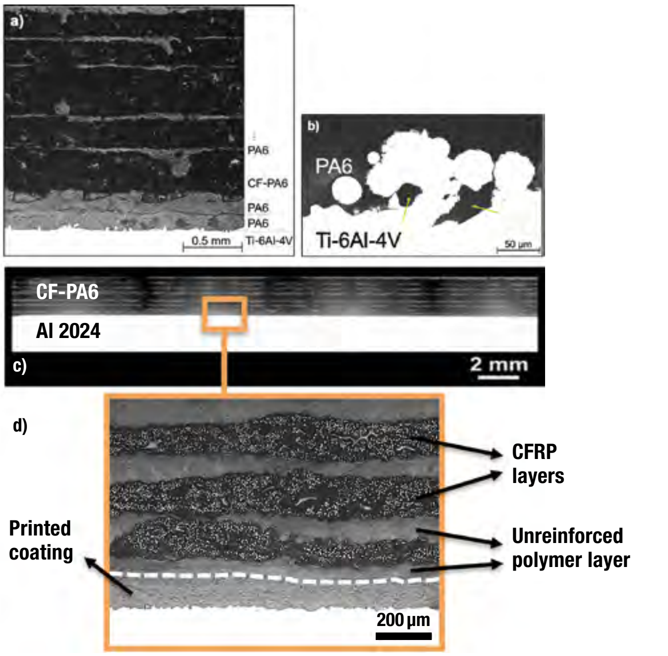

Figure 9: Example of Add-joints: a) CF-Polyamide 6 and Ti-6Al-4V printed with laser powder bed fusion; b) detail of the interface of specimen in a); c) overview of the cross section of a CF-Polyamide 6/Al 2024 Add-joint.

Photos: a) b) C. Belei, 2021, c) R. Falck, 2020.

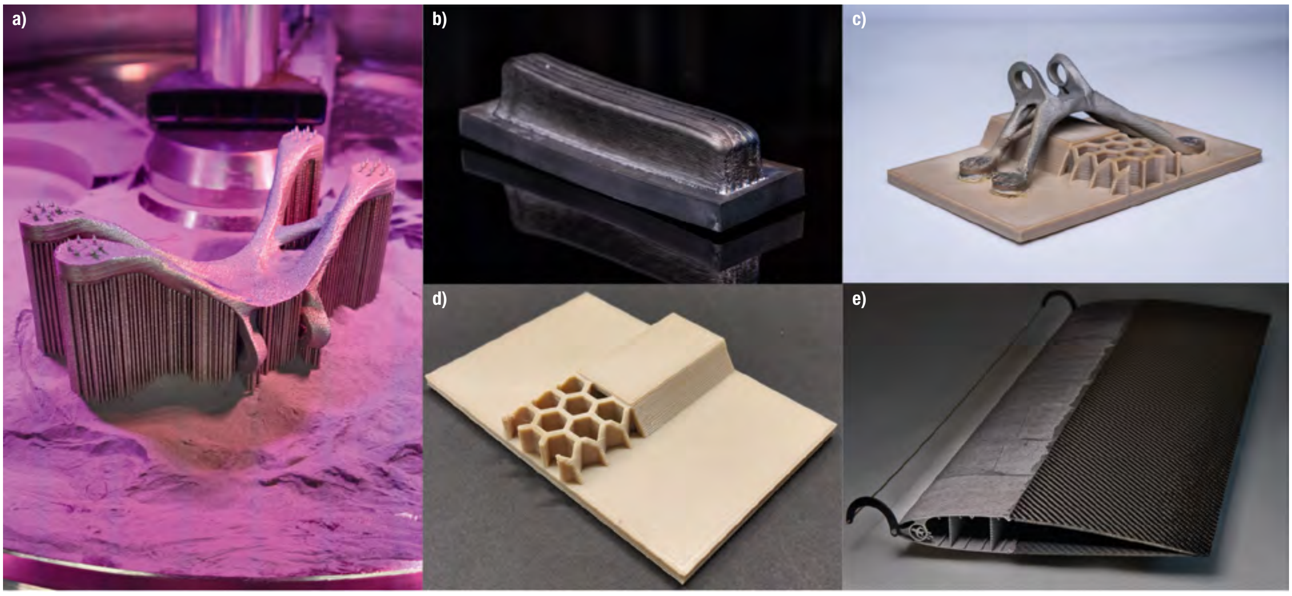

Figure 10: Additively manufactured and joined metal, polymer and metal-composite hybrid parts: a) Laser-Powder Bed Fusion (LPBF), 316L stainless steel; b) Wire-Based Electron Beam Additive Manufacturing (w-EBAM), NiTi shape memory alloy; c) Ultrasonic Joining of FFF-PEEK with LPBF 316L stainless steel; d) Fused Filament Fabrication (FFF), PEEK; e) Additively manufactured Al-CFRP wing for Ion-propulsion drone (FFG project Ionas I).

Photos: a) W. Carvalho, b) C. Hoflehner / R. Paiotti, c) C. Hoflehner / W. Carvalho, d) W. Carvalho, e) L. Minkowitz/ S. Arneitz/ S. Fortmüller.

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