FRAUNHOFER-INSTITUT FÜR WERKSTOFF- UND STRAHLTECHNIK IWS

TECHNOLOGICAL DEVELOPMENTS FOR THE AVIATION AND AEROSPACE INDUSTRY

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Driven by the reliability of stressed lightweight construction and the tireless quest for the latest material developments, the aerospace industry represents one of the most influential economical and scientific forces. Fraunhofer IWS Dresden supports their endeavors by developing industrialized solutions, new technical approaches and evaluation procedures.

Portfolio

- Additive Manufacturing.
- Welding of Al and Ti alloys with laser beam and friction stir processes.
- Industrialization of large-scale and complexly shaped 3D components.
- Laser cutting and bonding of carbon reinforced polymers.
- Microperforation of ceramic metals and thermo cycling of ceramic and metallic coatings.
- Wear protection and thermal insulation.

Additive Manufacturing

Thanks to a wide range of new applications such as load-oriented complexly shaped parts, Additive Manufacturing (AM) provides the aviation and aerospace industry with solutions triggering considerable weight loss and cost savings. Fraunhofer IWS offers the main metal additive manufacturing processes:

- Powder-bed based: Selective Laser Melting (SLM) and Electron Beam Melting (EBM).
- Nozzle-based with powder or wire: Laser Metal Deposition (LMD).

We cover the complete CAD-CAM process chain from design to final part for these technologies. Core research topics include the manufacturing of load-optimized structures, large-scale components, micro components and hybrid structures. Fraunhofer IWS scientists are experienced

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in aerospace related qualification and validation procedures including comprehensive in-house testing and analysis.

Small structures – great effect: Already today, a Fraunhofer IWS AM technology helps to extend service intervals as well as to reduce fuel consumption and emissions of modern jet engines. Filigree structures made by Additive Manufacturing increase the endurance of Thermal Barrier Coatings (TBC) in jet engines in order to help withstanding temperatures over 1000 °C. The potential resulting from the development of these structures opens up new applications beyond the field of engines.

Applied research partner of ESA GSTP: Fraunhofer IWS enables German small and medium enterprises to use advanced Additive Manufacturing. The projects include redesigned and topology-optimized space parts manufactured by using SLM, EBM and LMD.

Space parts with SLM and LMD: The right AM process required for the right application: Fraunhofer IWS manufactured a thrust nozzle with integrated conformal cooling channels by using SLM, suitable for complex geometries. An LMD-manufactured combustion chamber uses the beneficial high build-up rate and possible large dimensions of near-net-shape parts.

Laser Beam Welding (LBW) joining techniques

Consistently applied light weight constructions require modern joining procedures such as laser beam and friction stir welding or adhesive bonding. These techniques constantly find their way into fields such as aircraft-, rocket-, engine-, and satellite construction. A most promising technique is laser beam welding. Fraunhofer IWS especially focuses its efforts on developments for difficult-to-weld Al-,Ti- and Ni-alloys as well as for intermetallic composites.

LBW of aircraft fuselage structures: A most essential aim for the production of airliners is reducing weight and production costs. Laser beam welding of stiffener elements in fuselage structures can contribute to a high degree. Due to the seam formation, stress and distortion, two-beam welding is applied simultaneously and from both sides. With two unique machines for laser beam and friction stir welding we are able to join three-dimensionally up to ten by three by one meter parts with filler wire using laser beam welding with a moving clamping device and sensor technology. Combined with a high automation degree these yield great potential cost savings as well as reproducibility. The bed optionally operates with two 4.5 kW-CO_2 lasers of highest beam quality or two modern solid state lasers such as fiber or disk lasers.

Friction Stir Welding (FSW) joining techniques

For high strength materials with restricted fusion weldability, friction stir welding offers new technological approaches for aircraft structures. The technique is known for its many advantages in terms of tensile strength and joint damage tolerance, but also for its challenges, when welding three-dimensional contours, large structures, limp parts or a combination of those. Fraunhofer IWS is developing and using novel machine concepts to overcome these challenges. Especially for large aircraft components a special lean tooling concept was developed. This helps customers to explore new design capabilities for light-weight and efficient part designs. Furthermore, due to reduced machine investment costs, these concepts can also reduce their investment during industrialization of the process.

FSW of large aircraft components: The novel MUVAX system is developed for joining large aircraft components by friction stir welding. As no backing bar is needed in the application process, preconfigured parts with mounted stringers and frames inside can be processed. The demonstrator machine at Fraunhofer IWS is capable of handling three-dimensional curved parts of up to nine meters in length. The robot can be equipped for FSW, milling and NDT. This way one robot is able to perform all relevant pre- and post-processes within one clamping.

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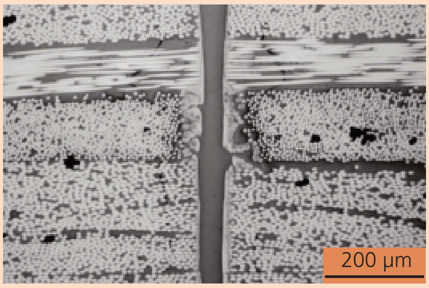
Weld seam evaluation improves components and processes: Weld seams are very often the weak point in highly stressed components. Partially based on FE simulation, a solid knowledge of their effects and property-controlling factors helps to find solutions for selecting the welding process, fillers, seam positions and the development of quality assurance (QA) concepts.

Adhesively bonding textile reinforced construction materials

Fiber reinforced thermoplastics are fabricated using hybrid yarns, e.g. made from polypropylene and glass fibers. Such processes are used to manufacture two- and complex three-dimensional structures. The hybrid yarn textile thermoplastic composite technology for lightweight construction applications requires appropriate joining techniques. Adhesive bonding processes offer a larger connection area with uniform load transfer. However, polyolefin materials such as polyethylene and polypropylene have low energy surfaces and thus tend to show low affinity to adhesives. Therefore, the surfaces of these materials have to be effectively pretreated to improve adhesion. The Nd:YAG laser generates specific surface structures, which depend on processing parameters such as spot size and track overlap. Atmospheric pressure plasma and laser processing significantly increase the performance of the adhesively bonded joints in comparison to ethanol cleaned samples. An artificial climate change test also showed an improved ageing resistance for laser treated samples.

Remotely processing carbon fiber reinforced polymers

Carbon fiber reinforced materials (CFRP) combine high specific tensile strengths with low densities leading to a broad application potential. Fraunhofer IWS engineers developed highly dynamic beam deflection systems to significantly improve the laser process efficiency in order to treat high performance polymer-based fiber reinforced composite materials. A fast mirror system based on galvanometer scanners is used to rapidly project the laser beam onto the material. The mirrors operate very precisely even at very high path velocities. Due to high processing speeds the shortened laser interaction with the composite material reduces the thermal decomposition of the matrix material. This leads to better ablation and cutting results.



Cutting joints of a carbon fiber reinforced material after beeing cut with highly dynamic beam scanning.

Microperforation for ceramic metal joints: New high-strength, lightweight materials like fiber reinforced ceramics are increasingly applied in aerospace, especially for highly stressed components. To integrate the new ceramic components into the prevalent metallic structures, new joining methods are essential. Creating microperforation with the ceramic components' surface is necessary for developing an adapted soldering technique. Laser ablation utilizing short pulsed solid-state lasers generates blind hole structures of adjustable contour and depth. The focused laser beam predominantly rates the material like carbon fibers as well as silicon carbide. After intensively optimizing the laser ablation parameters, a process with minimal thermal damage to the surrounding material could be realized. The developed laser perforation process and the subsequent soldering are applied to prototype components as well as to produce single items in the satellite manufacturing to realize e.g. steering nozzles or stiffening elements. Metal ceramic joints based on the laser microperforation process have been extensively tested. They reach strength levels three times higher than the base material.

Technologies for wear protection and thermal insulation

Tailor-made coating solutions for the aviation industry made by Fraunhofer IWS are based on modern efficient spray and surfacing processes:

- Spraying: Cold gas and suspension technologies.
- Build-up welding: laser-based methods.

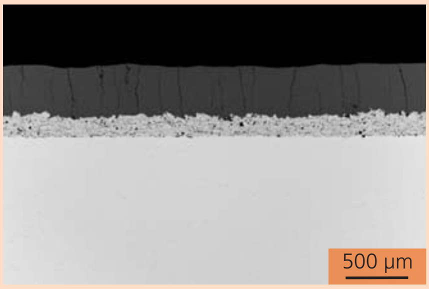
The applications at hand range from surface coating to repairing to generating. The user receives everything from one source: the coating solution itself and the tools required for its industrial implementation, such as laser processing heads for powder and wire, CAM software, sensors as well as on-site commissioning and training. The materials range from metal alloys to hard metals to ceramics. Examples include thermal barrier coatings, layers with electrical function, armor and efficient repairs of damaged engine components.

Surface hardening: Ti-alloys or particular steels (precipitation hardenable or maraging) are often used for components exposed to high static or cyclic stress. As their wear resistance often proves too small, two novel surface hardening procedures were refined and developed:

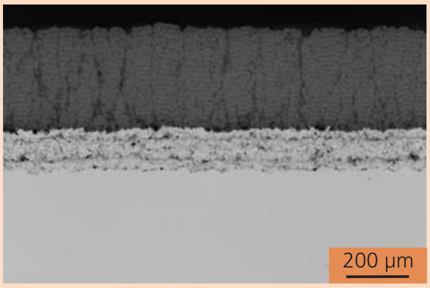
- Laser gas alloying under controlled atmosphere.
- Laser surface solution annealing with subsequent precipitation hardening.

Suspension sprayed TBCs: Thermal barrier coatings (TBCs) belong to the most promising applications for suspension thermal spraying. Coatings with columnar-like or vertically segmented cracks (VC) morphology can be produced under atmospheric conditions. In both cases the obtained properties show promising results in direct comparison with traditional atmospheric plasma sprayed coatings (powder feedstock) or electron-beam physical vapor deposition coatings (deposited under vacuum).

Thermal cycling resistance of coatings: Knowing the thermal cycling resistance is a necessary asset when improving efficiency and controlling the partly extreme heat flux density, temperatures and their gradients in components of jet and rocket engines. Specially developed laser-based testing methods simulate these stresses and detect the damage process either on-line by acoustic emission analysis and high speed photography or off-line by ultra-sonic and mechanical tests. This way Fraunhofer IWS is able to suggest properties' improvements.



YSZ TBC water-based S-HVOF.



YSZ TBC alcohol-based S-APS.

Cover picture

Source: shutterstock

1 The thruster nozzle segment has been additi vely manufactured from stainless steel (14.4404) by means of selective laser melting (SLM) technology.

2 The MUVAX system enables friction stir welding of demonstrator parts.

3 High velocity flame spraying using suspensions.