

# LeiMot: Application of Self-Tapping Screws in an Additively Manufactured Multi-Material Engine

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Research institutions worldwide are investigating lightweight construction as a key technology for more efficient, carbon-neutral transportation. Within this field, the LeiMot project seeks to achieve a substantial reduction in engine weight by combining multi-material components with novel manufacturing methods. The project is funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK) [1].

The proposed engine concept [2] combines additively manufactured AlSi10Mg0.4 aluminum alloy for highly loaded components with injection-molded, fiber-reinforced thermoset side covers (Figure 1). Integrating oil and coolant channels into the component design reduces weight and lowers costs through functional integration. Implementing this multi-material arrangement also requires suitable joining technologies. On the intake side of the engine, shown in black on the right in Figure 1, screw fastening was combined with adhesive bonding. In this joint, the adhesive additionally serves as a sealant to prevent leakage [3].

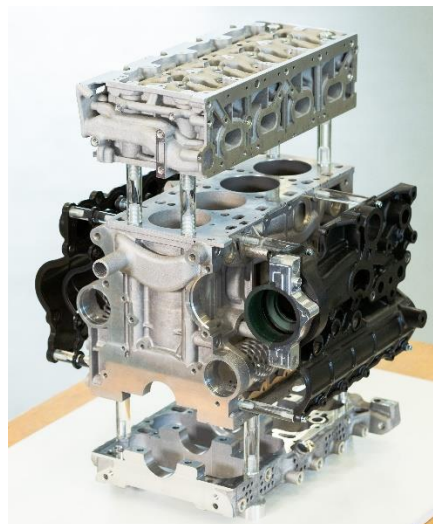


Figure 1: LeiMot engine

The high vibration levels generated by the engine require joints with a pronounced self-locking effect. Self-tapping screws offer an attractive solution, combining strong self-locking properties with installation that requires no previously cut thread (Figure 2).

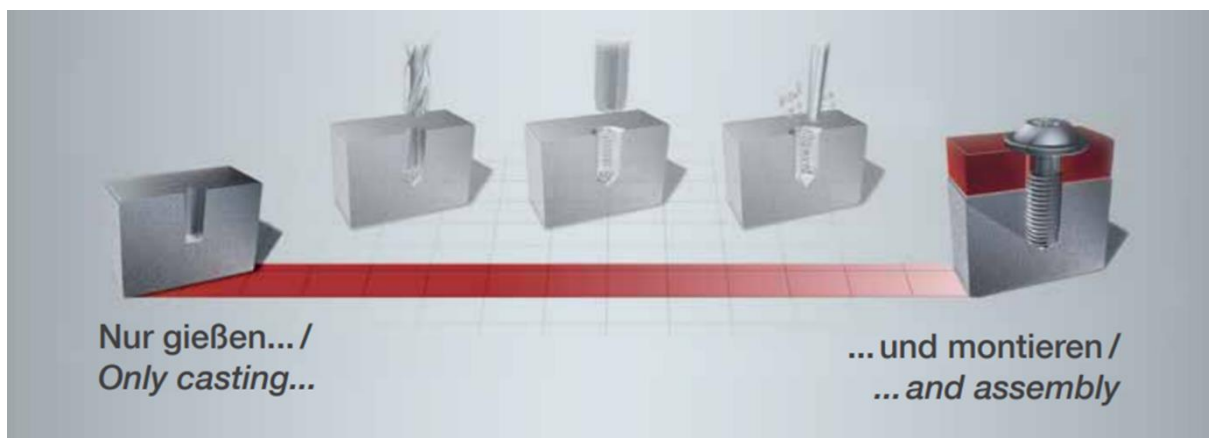


Figure 2: Advantages of self-tapping screws [4]

Incorporating the core holes into the engine design before machining reduces processing time, costs, and material consumption. The special tip geometry of self-tapping screws allows installation without an additional thread-machining step. These screws are not covered by standards and are available in several configurations for different applications. Compatibility with metric screws is another feature. Since the technology was originally developed for cast materials, its suitability for additively manufactured alloys remained to be investigated.

FEV addressed this question together with the Fraunhofer Institute for Chemical Technology (ICT) and the screw manufacturer EJOT, with the aim of developing an assembly solution for the intake-side cover. The high cost of LeiMot prototype engines made preliminary testing necessary before the technology could be applied to an engine.

Casting cores require a conical bore geometry, with a 3° taper, to permit removal after casting. As ALtracs screws were developed for cast alloys with conical core holes, the initial tests on specimens produced by laser powder bed fusion (LPBF) adopted this established geometry. LPBF does not involve demolding, however, and therefore also permits cylindrical bores. Specimens incorporating this alternative bore geometry were consequently printed as well.

The first phase examined whether self-tapping screws function effectively in an additively manufactured alloy. Unlike cast material, LPBF material exhibits anisotropy associated with the orientation of the component during manufacture [5]. This influence was considered by producing specimens in both vertical and horizontal build orientations, as illustrated in Figure 3.



Figure 3: Specimens used to test ALtracs Plus screws

The inner diameters produced by LPBF were reproducible within 3% for horizontal builds and within 1% for vertical builds. A reference for the established application was provided by a wrought-aluminum block containing several machined M5 core holes. To assess reusability, each screw was subsequently removed and reinstalled five times in both the additively manufactured specimens and the machined aluminum reference specimens.

Successful use of the self-tapping fasteners in the additively manufactured alloys was demonstrated by the tests. Only negligible differences in preload force and tightening torque were observed among the three specimen groups. In addition, the measurements for the additively manufactured specimens showed less scatter than those obtained from the aluminum block.

The subsequent phase incorporated the thermoset cover and the silicon-based adhesive into the investigation. Sufficient bearing area beneath the screw heads was required to distribute the loads uniformly. Because preload forces exceeding 4 kN could induce microcracking and damage the cover, an appropriate tightening torque had to be established. Pressure on the cover also causes the screws to elongate, creating a gap. The adhesive must therefore maintain sealing under the operating pressure.

Test boxes were developed to investigate these requirements (Figures 4 and 5). Their screw spacing, wall thickness, and stiffening rib reproduced the region highlighted in green on the intake cover. The covers were injection-molded using the thermoset material specified for the engine side covers, while the main bodies were milled from aluminum to represent the materials of the engine assembly.

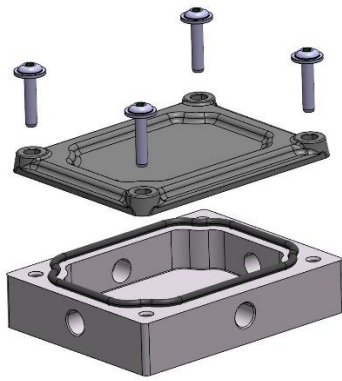


Figure 4: Components of the test box

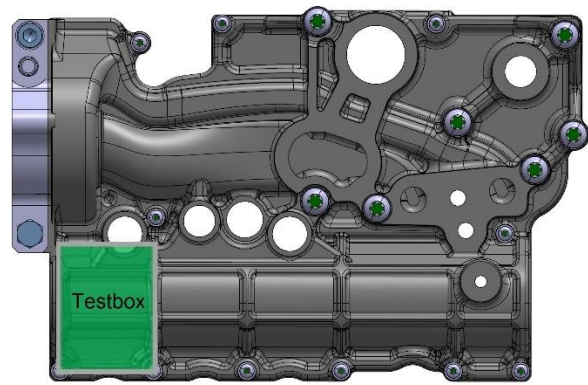


Figure 5: Intake-cover region represented by the test box

A glycol-water mixture was pumped into the boxes to reproduce coolant pressure. Thermal loading was introduced by placing a box on a heating plate with adjustable temperature. This arrangement represented engine warm-up, when transient temperature differences between the aluminum crankcase and the thermoset side cover impose the highest loads on the cover and seal.

Preparation of the test housings began with drilling holes into the aluminum. The previously observed similarity between the additively manufactured tubes and the wrought-aluminum block supported this approach. The self-tapping screws were then used to produce the threads and subsequently removed. After application of the adhesive and positioning of the cover, the components were assembled again with the same screws.

The procedure was repeated ten times for three test boxes to establish the tightening torque corresponding to a maximum preload force of 4 kN. The tests further showed that the screws could be reused at least ten times without changing the retightening torque needed to achieve the required preload.

The final step subjected the boxes to combined pressure and temperature loading. Both quantities were increased along the vapor-pressure curve for a 50/50 glycol-water mixture until either cover failure or leakage occurred. Figure 6 illustrates the experiment [6].

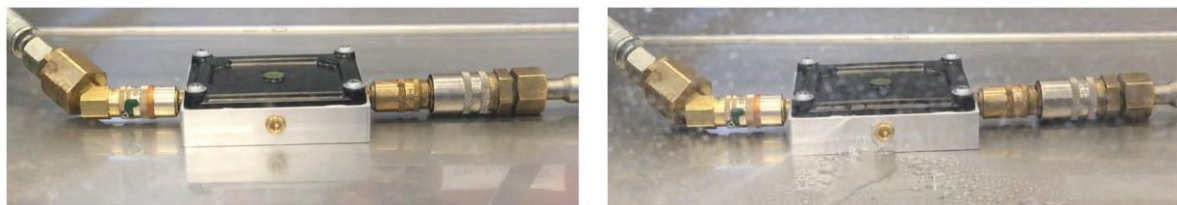


Figure 6: Test-box experiment before and after failure

Failure of both the cover and the adhesive occurred at loads above those required, enabling the joint concept to proceed to engine testing. Two LeiMot engines were assembled using 11 EJOT ALtracs Plus AP50x20/15 screws, marked in green in Figure 7. Following printing, the screws themselves produced the threads at a rotational speed of 300 rpm and a torque setting of 4.5 Nm. The screws were subsequently removed to allow placement of the thermoset intake-side cover. Final installation was performed at 100 rpm with a maximum retightening torque of 3 Nm.

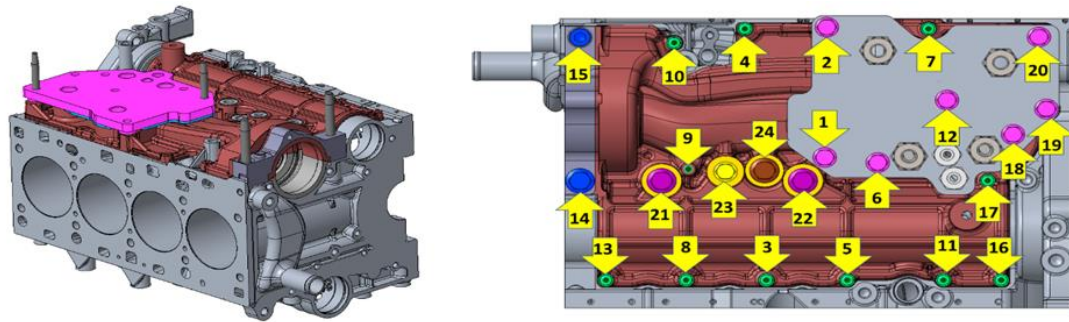


Figure 7: Arrangement of the screws

Figure 8 presents the data acquired as the self-tapping screws produced the threads.

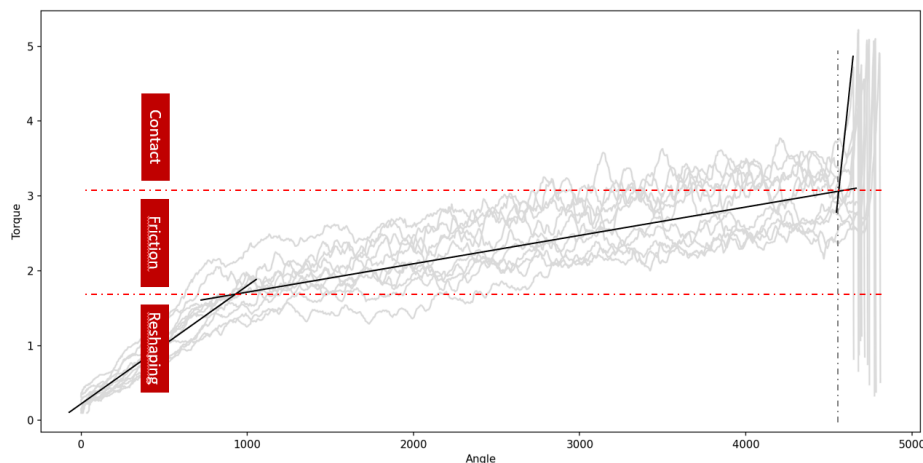


Figure 8: Torque response during thread generation with self-tapping screws

The recorded response comprises three characteristic stages. Material is initially reshaped by the leading portion of the screw thread. This is followed by a stage governed by friction between the thread and the main body. Contact of the screw head with the main body marks the third stage, in which torque increases exponentially. Comparable scatter in rotation angle and torque across the different screws indicates that the assembly process is reproducible.

## CONCLUSION

This study investigated the application of self-tapping screws to additively manufactured aluminum components. It formed part of the LeiMot project, which pursues innovative lightweight designs for improved vehicle efficiency and receives funding from the German Federal Ministry for Economic Affairs and Climate Action.

Validation followed a three-stage test program. The initial stage compared screw installation in additively manufactured aluminum with printed core holes, additively manufactured aluminum with machined core holes, and forged aluminum with machined core holes and threads. Negligible differences between the results supported the use of forged-aluminum test boxes fitted with thermoset covers in the second stage. These assemblies were used to examine preload in combination with the structural adhesive under thermal and hydraulic loading. In the final stage, two additively manufactured LeiMot engines were assembled with EJOT ALtracs Plus AP50x20/15 screws while torque was recorded as a function of rotation angle. The expected screw performance was achieved, completing the final test successfully.

Quantifying the productivity improvement would require further trials under series-production conditions. Such trials are not yet feasible because additively manufactured engines remain a novel development. Nevertheless, the project provides a proof of concept for combining fastening technology with additive manufacturing. The approach can also be transferred to other applications requiring lightweight construction, both within the transportation sector and beyond.

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