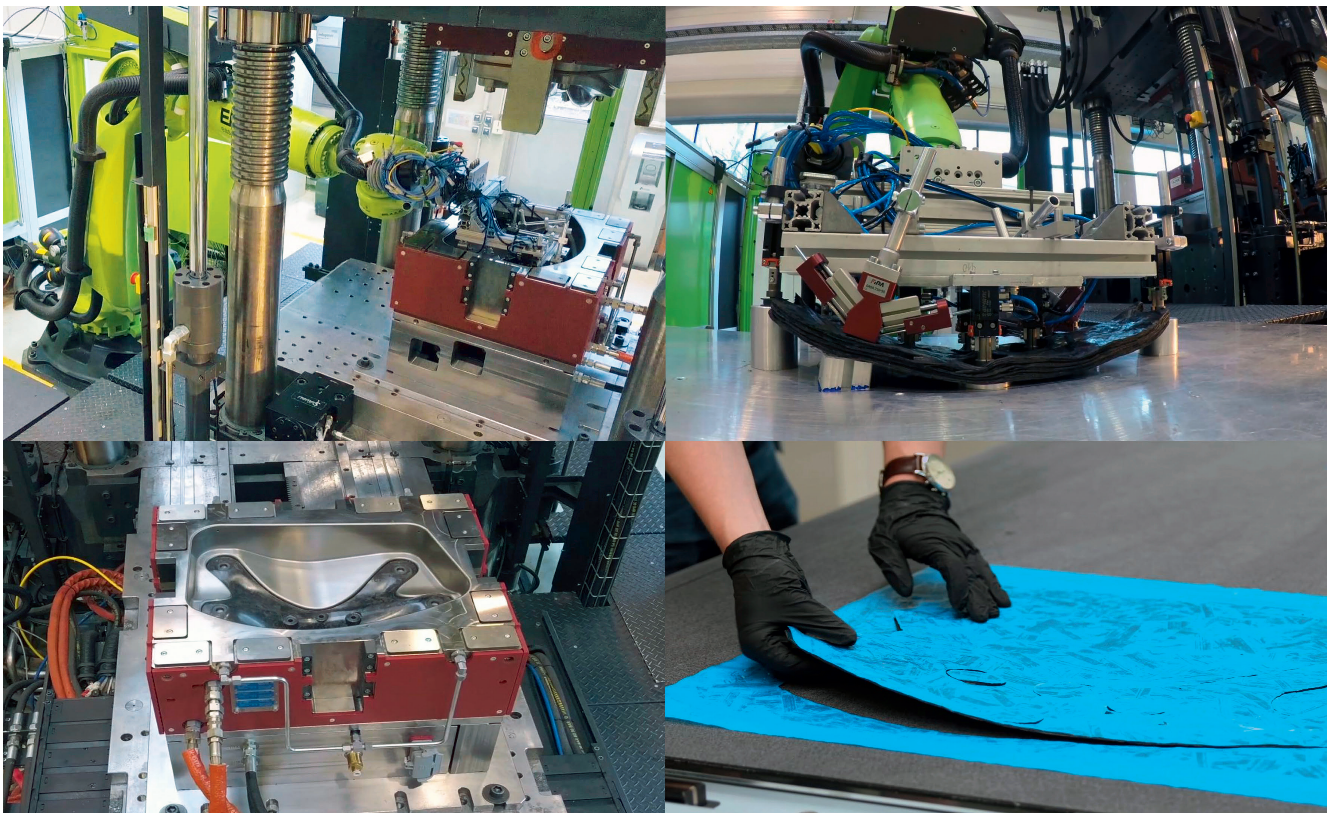
Zero-Waste Concept for Carbon SMC

A Research Project Highlights the Recycling Potential of Lightweight Composites

Composite materials are often the key to lightweight design for many applications. However, these hybrid materials face a major challenge where recycling is concerned. There is still no solution to the recovery of long and continuous fiber-reinforced materials. Where it is possible at all, only downcycling has been feasible until now. Four research partners have therefore set themselves the goal of developing a new press forming technology as part of a zero-waste project.



The experimental components were manufactured in a fully automated SMC manufacturing cell, developed by Engel, with an Engel v-duo 700 machine and an easix KR35 articulated robot © Engel

Whether for automotive, aeronautical, teletronics, construction or technical applications – diverse industries require ever more lightweight designs together with ever better part properties. The obvious advantage of using composite materials often fails at the hurdle of recycling. Three companies – Engel Austria GmbH, St. Valentin, Alpex Technologies GmbH, Mils, both in Austria, and the Hexcel Corporation, based in Stamford, CT/USA – are working on a solution together with Johannes Kepler University in Linz, Austria.

The research work focused on manufacturing carbon fiber-reinforced sheet molding compounds (SMC) by hot press forming, abbreviated to carbon-SMC, or C-SMC technology. The one-step process is regarded as especially cost efficient, in both its fully and partly automated versions. Critical regions are reinforced locally, in line with the load paths, by means of fiber-reinforced prepregs.

The project, which was sponsored by the Austrian research funding association (FFG), operates at various levels. It concerns the use of recycling materials, reduced quantities of carbon fiber waste, cost-optimized manufacturing and greater material efficiency. The goal is to use material only where it is required by the loads and safety requirements.

From the Idea to the Automotive Component

The processing concept for manufacturing fiber composite solutions with a focus on zero waste was first validated at laboratory level, with both recycled carbon fibers and SMC offcut wastes. To permit implementation in large series, fully automated press forming was preferred from the start. The case study, an automotive transmission crossmember, effectively illustrates the feasibility and market potential of the innovation (**Fig. 1**).

The structural component, which is traditionally made of aluminum, was developed from carbon SMC with the premise of zero waste. The part specifications were provided by a leading OEM and the component design was optimized for the material. During the product creation, the development partners developed approaches to process and structural simulation. They were able to determine essential process data in advance by means of trial components. This reduces the development work and increases process reliability.

As the component topology was optimized at the beginning of the project, the main priority was to adapt the new process to the particular characteristics of the material. Different SMC semi-finished materials from Hexcel were used, some of which are still at the development stage. Various sandwich architectures were also used. The reference material was HexMC-i 2000, a commercially available carbon-SMC type. The feasibility as a whole was evaluated with four different materials (**Fig. 2**):

- HexMC-i 2000 is given the designation primary C-SMC. It consists of rectangular chips (50 x 8 mm) cut from continuous fiber-reinforced, unidirectional (UD) carbon-fiber prepregs. The chips have a random orientation in the sheet molding compound.
- rC-SMC is designated secondary C-SMC and contains recycled carbon fibers from the US supplier Carbon Conversions, which are impregnated with epoxy resin in a prepreg line at Hexcel. The carbon fibers have an irregular structure, similar to conventional GF-SMC.
- UD tapes with an epoxy resin matrix were obtained from primary unidirectional carbon fiber prepregs and used for local reinforcement of HexMC-i 2000, which is made from the same material.
- C-SMC Prepreg Byproduct is obtained from the UD prepreg HexPly M77 (offcut waste from the industrial mass production of automotive components). As delivered, it is in the form of tapes, which are cut at distances of 50 mm. This material allows defined fiber orientations of the chips to be integrated into the component architecture.

Fig. 1. The case study, a transmission crossmember, illustrates the market potential of the zero-waste development. The C-SMC component (illustrated) weighs only half as much as the aluminum version © Engel

All the materials were pre-impregnated with the same epoxy resin (type: Hexcel M77). This resin system cures at 150 °C in about 2 min and is therefore especially suitable for automotive applications.

Fully Automated Process in the SMC Manufacturing Cell

The experimental components (**Fig. 3**) were manufactured in a fully automated SMC manufacturing cell, developed by Engel, an injection-molding machine with compression function »

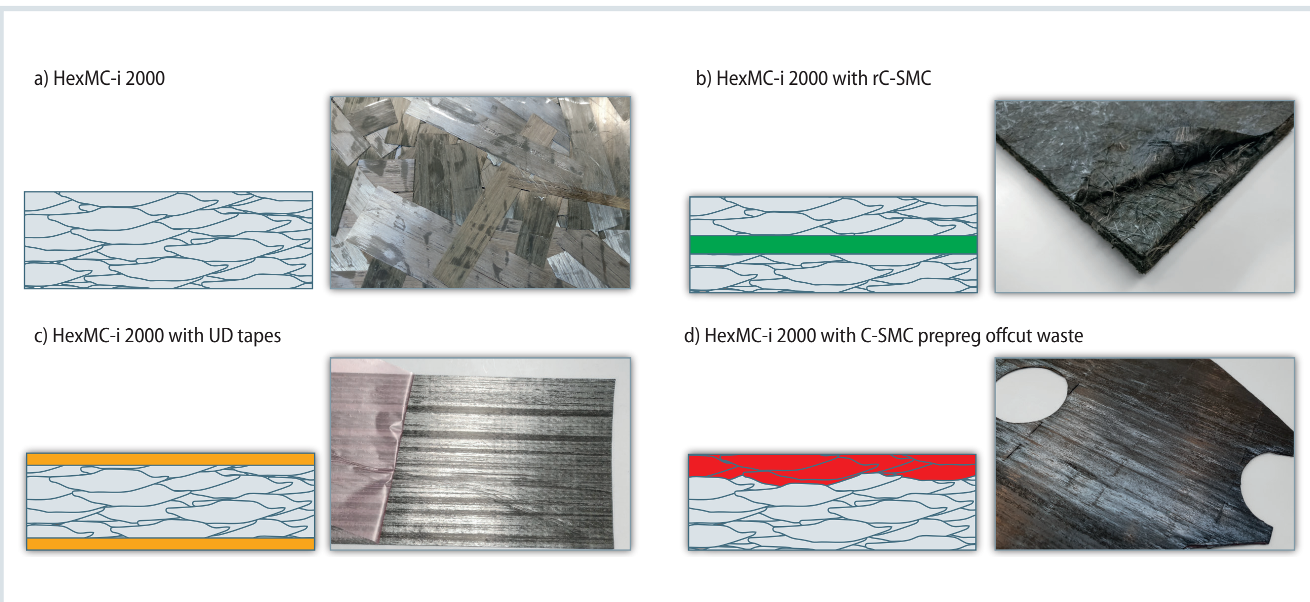


Fig. 2. The tests were performed with different materials. The reference material was HexMC-i 2000, a commercially available carbon-SMC type

Source: Johannes Kepler University; graphic: ©Hanser

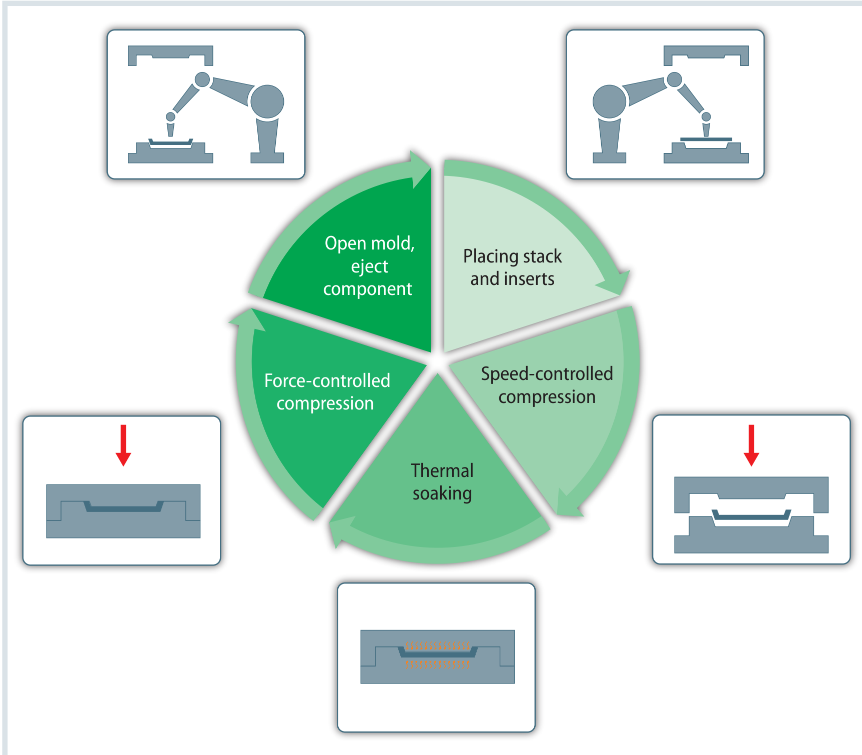


Fig. 3. In the optimized C-SMC press forming, the actual pressing of the material is performed following an approx. 15 s compression phase Source: Engel; graphic: ©Hanser

	Industry reference	Zero-waste approach	
	Die-cast aluminum	C-SMC	rC-SMC
Weight [g]	2500	1280	1270
Weight saving potential [%]	–	49	50
Critical load path (-Z) [kN]	> 21	26	30
Performance [%]	–	+26	+30

Table 1. The comparison of material and technology between die-cast aluminum and carbon SMC confirms the success of the zero-waste concept Source: Engel

(type: Engel v-duo 700) and an articulated robot (type: Engel easix KR35) (**Title figure**). The blanks were prepared on an NC-controlled cutting table, gravimetrically adjusted and introduced into the mold together with the aluminum inserts for the fastening points (**Fig. 4**). The mold is from Alpex, a supplier of tooling systems for manufacturing composite parts.

The carbon-SMC was pressed with a clamping force of 5000 kN. The resulting cavity pressure was in the range from 200 to 300 bar. With a component thickness of 8 mm and maximum dimensions of 520 x 340 x 100 mm, part weights of 1270 up to 1280 g were measured. The cycle time was 180 s. The actual press forming of the material was performed after a 15 s compression phase at 8 bar cavity pressure. The UD tapes were positioned before the stacks were inserted into the mold.

Validation of the Zero-Waste Concept

To validate the zero-waste concept, the structural components were mechanically tested in the laboratory on a servohydraulic testing machine (type: MTS Damper Test System; manufacturer: MTS Systems Corporation, Eden Prairie, MN/USA) according to the OEM's specifications. The component test rig modeled the connecting points to the actual body. The force was applied via the piston of a dummy transmission. The displacement and reaction force were determined using a load cell.

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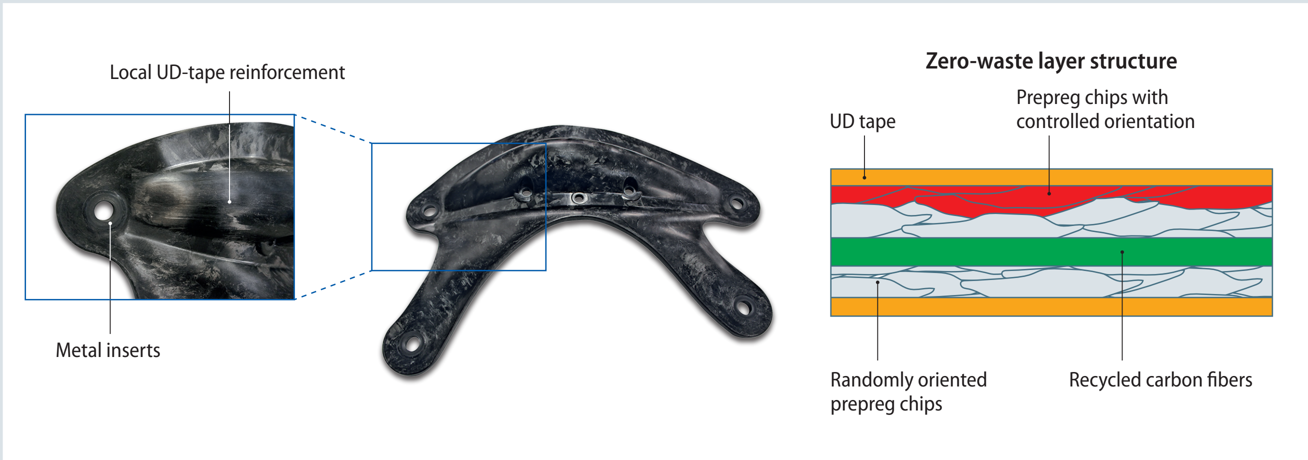

Fig. 4. The zero-waste sandwich structure was locally reinforced with a UD tape For the fastening points, aluminum inserts were introduced into the mold Source: Johannes Kepler University; graphic: ©Hanser

The component behavior under monotone, quasistatic loading was investigated by means of a critical load path in the Z-direction with a test velocity of 2 mm/min. To estimate the expected lifetime under service conditions, cyclic fatigue tests were performed in the critical Z-direction (**Fig. 5**). These tests were performed under sinusoidal loading (5 Hz), both displacement and force controlled.

Optimized Press Forming

The first investigations already helped to optimize the process sequence with the new SMC processing technology. The fact that the fibers are bound in the form of chips instead of taking the form of bundles or cut rovings significantly changes the processing behavior compared to the conventional carbon-SMC process. Only after a defined heating time does the viscosity of the matrix fall to a level at which the chips can slide with respect to one another. In the optimized process, therefore, before the actual press forming, the system is subject to a low pressure of approx. 8 bar for about 15 s until the stack reaches a core temperature of at least 60 °C. In addition, the pressing force is increased to cause the material to flow during subsequent pressing.

A graph illustrates the profile of the cavity pressure during the curing time. The reference material is shown in green and the recycled material in orange (**Fig. 6**). During the heating time, the cavity pressure is still low. In parallelism-controlled press forming, a pressure maximum occurs which, despite precise control of a constant clamping force of 5000 kN, rapidly decreases again. Here, the conversion of the liquid resin to the stiff and solid component at the pressure sensor influences the result of the measurement. In the continuation of the curing reaction, the pressure rises again, which can be primarily attributed to the thermal expansion of the C-SMC. Toward the cycle end, the pressure curves converge because of the identical matrix material.

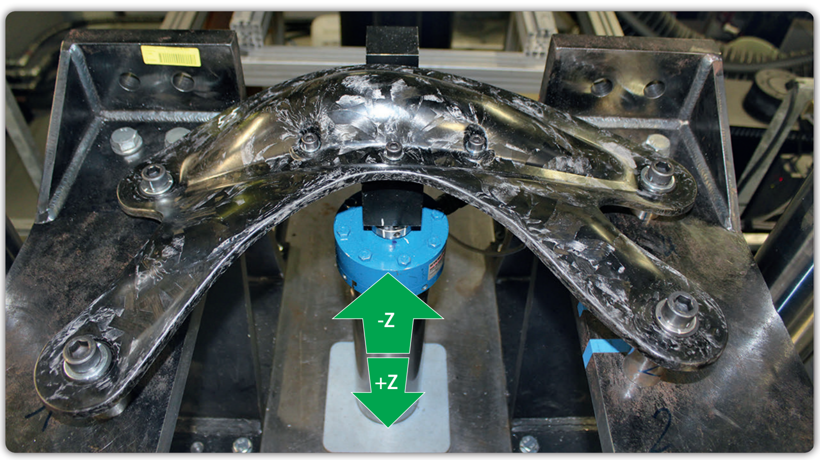

Fig 5. The structural components were mechanically tested on a servo-hydraulic test machine according to the OEM's specifications. Z was declared as critical load direction © Johannes Kepler University

Benchmark with Different Materials

In another series of experiments, the four investigated material configurations were compared with one another. The component tests were performed on a transmission dummy test rig. The readings for the comparison obtained from the quasistatic component test were the linear stiffness, the secant stiffness at the force maximum, and the fracture load (**Fig. 7**).

Although the measured values are technical characteristics, which only apply to the part-specific test configuration, they permit comparisons between the test specimen and material variants. The results are standardized to the material configuration HexMC-i 2000, in which all three characteristic values receive the value 1, i.e. 100 % (**Fig. 2a**).

With the use of recycled carbon fibers (**Fig. 2b**), or secondary C-SMC from industrial UD prepreg offcut waste (**Fig. 2d**) » in a layer structure with primary C-SMC, properties are obtained that are at least just as good as those found with the primary reference material HexMC-i 2000 (**Fig. 2a**). An important goal of the zero-waste concept was thus achieved. In this manner, the amount of carbon fiber waste can be considerably reduced without a significant loss in component performance.

With the use of UD tapes (**Fig. 2c**) and controlled orientation of the chips (**Fig. 2d**), the stiffness could be increased and its standard deviation reduced to less than half. However, these measures did not improve the component strength. The fracture strength was critically depended on the clamping conditions and the strength of the weld seams, if present. In this case, there was intense scattering (variation coefficient from 10 to 20 %), which showed little correlation with an alternative layer structure or variation in the process control.

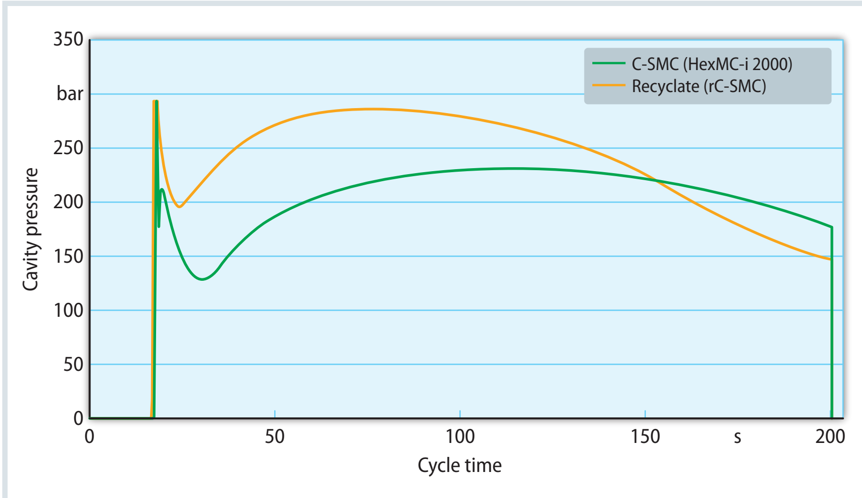

Fig. 6. In the manufacture of the transmission crossmember, the cavity pressure was measured over the entire curing time Source: Engel; graphic: ©Hanser

Approx. 50 Percent Weight Saving

All variants meet the failure load of 21 kN required for the specific application, with maximum values of over 26 kN being obtained, as is shown by a material and technology comparison with the example of a transmission crossmember component (**Table 1, see p. 20**). The primary C-SMC material, as well as the recycled C-SMC, meet the automotive manufacturer's quasi-static component specifications (stiffness, strength). The zero-waste concept can thus be used as a contribution to increasing the recyclate content in load-bearing components.

The component tests demonstrate that the fracture loads in the critical loading direction lie well above the specified values of 21 kN. Dynamic endurance tests on the transmission crossmember do not show any damage of the C-SMC material after three million cycles, which highlights the materials' potential suitability for structural applications in vehicles. However, the process of integrating the aluminum insert requires further optimization. Compared with the aluminum component, a weight saving of about 50 % could be obtained.

Compression Function is Mission Critical

The manufacturing of the test parts depended for its success on the use of the compression function of the Engel v-duo 700 machine, which achieved a precise force- and parallelism-controlled heating and pressing phase. This leads to a reproducibly high component quality, which fully reveals the potential of this material class. ■

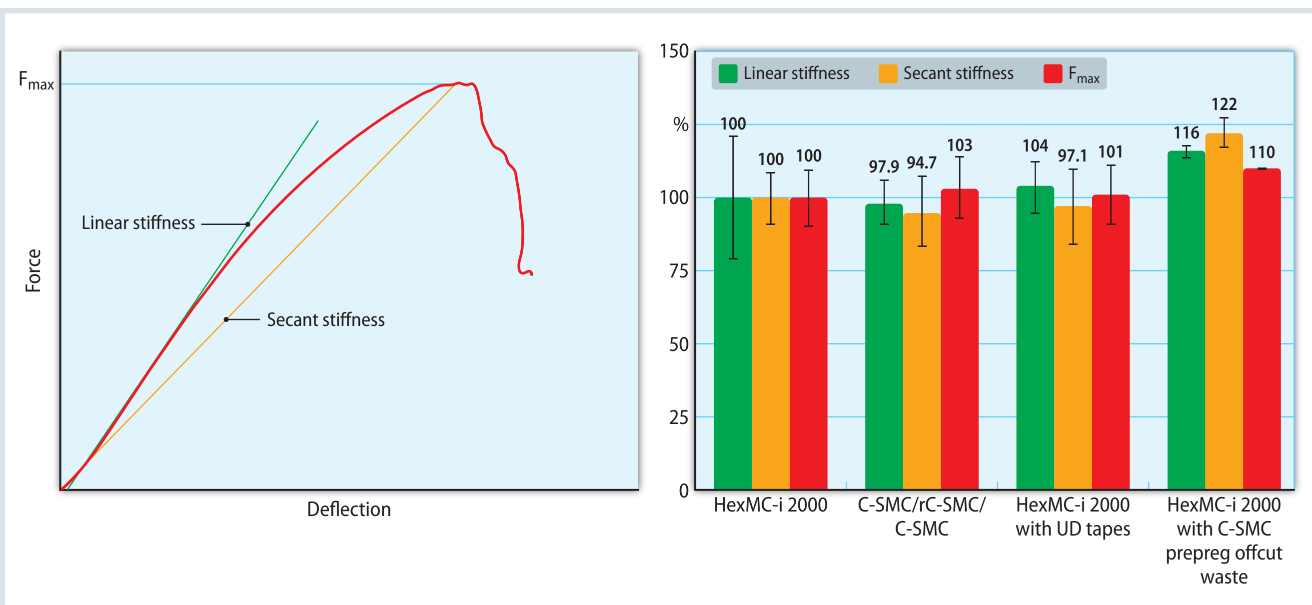

Fig. 7. In another series of experiments, the four investigated material configurations were compared with one another. The readings for the comparison were the linear stiffness, failure load (F_{max}) and the secant stiffness at the force maximum Source: Johannes Kepler University; graphic: ©Hanser