Research on mechanical and sensoric set-up for high strain rate testing of high performance fibers

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Abstract. Within this research project, the tensile behavior of high performance fibers, such as carbon fibers, is investigated under high velocity loads. This contribution (paper) focuses on the clamp set-up of two testing machines. Based on a kinematic model, weight optimized clamps are designed and evaluated. By analyzing the complex dynamic behavior of conventional high velocity testing machines, it has been shown that the impact typically exhibits an elastic characteristic. This leads to barely predictable breaking speeds and will not work at higher speeds when acceleration force exceeds material specifications. Therefore, a plastic impact behavior has to be achieved, even at lower testing speeds. This type of impact behavior at lower speeds can be realized by means of some minor test set-up adaptions.

1. Introduction

Using high performance fibers, such as carbon fibers, for reinforcement in fiber reinforced plastic and concrete applications, the knowledge about the behavior of these fibers under high velocity impacts and crashes becomes increasingly important for designing and dimensioning new composite components [1]. The resulting strain rate of these fibers defines their failure behavior, which is more important than the impact velocity. Recent research activities on PA6.6 investigate the failure behavior of fibers at up to 70 m/s or 500 1/s. Due to the 20 times higher maximum breaking elongation of PA 6.6, the use of conventional force measuring cells for determining the material properties is possible based on longer measuring times. Actually, no tensile testing of fibers is performed at strain rates above 500 1/s nor velocities above 70 m/s. For non-textile materials, this test is typically performed using a split hopkinson kolsky bar. The flexible nature of fibers requires a tailored test set-up. The objectives of current research at ITM consist in achieving an increasing speed and strain rate with a rotating disk loading principle and thus in providing a trans-scale test set-up for quasi static to high dynamic stress. This contribution (paper) presents the development of an improved fiber bracket and a comparison of different load sensor principles based on preliminary tests as well as a simulation based approach.

Performing high speed tensile testing, two challenging issues occur very early in the process. The first issue is to apply the load to the test specimen properly so fiber breakage occurs under target speed. The second challenge is to capture the course of force during the test.
2. Experiment
To investigate the aspects mentioned above, two existing testing machines, Zwick HTM 5020 and a previously constructed drop tester [2], were used. Tests were carried out using the original testing machine (Figure 1) as well as a modified set-up (Figure 2). The carbon fibers used were Toho Tenax HTS 45 E23 12K with 800 tex and SGL Carbon Sigrafil 24K with 3300 tex. The force measurement was carried out by means of piezoelectric load cells (Kistler type 9071A, built-in in HTM5020 and Kistler type 9311B) with different resonance frequencies (less than 30 and 70 kHz, respectively). In addition, a location and time resolved motion analysis was carried out using the high-speed camera Photron SA-X2 and the software GOM Correlate.

Figure 1: Set-up of original testing machines: Zwick HTM5020, complete with standoff distance (left) and detail of clamp (center); drop tester with original clamp set-up (right)
Figure 2: Spring-damper-model (left), set-up of modified testing machines: Zwick HTM5020 (center) and drop tester (right) with tailored clamps and additional load cell.

Figure 3: Constructed drop tester with elastic impact behavior.

Figure 4: Constructed drop tester with an additional metal sheet to achieve plastic impact.
3. Results and discussions

A model of the test set-up was created in order to be able to theoretically analyze the testing machine behavior for varying parameters (Figure 2 left). Based on these investigations, optimized clamps were designed to lower the weight of the parts to be accelerated. Based on the original set-up, by means of motion analysis it was found that elastic impact occurs in most of the former tests (Figure 3), which is quite satisfying for the speed of these conventional testing machines. A disadvantage of elastic impact is that the resulting speed is up to 2 times higher compared to the speed of the incident bar, which may lead to wrong breaking velocities as shown in the diagram in Figure 3.

To achieve higher strain rates at constant specimen length, it is necessary to increase the testing speed. As a result, the energies required for accelerating one end of the sample are much higher. Therefore, the material behavior under impact changes to a partially plastic impact. To realize a defined impact behavior for high testing speeds, a pure plastic impact behavior has to be achieved. A corresponding modification is shown in Figure 4. On the left side, a metal sheet placed under the anvil converts the impact energy into plastic deformation and prevents further acceleration of the anvil by elastic deformation energy of the impact. On the right side, the velocity profile is shown with a steep ramp caused by the fixture of the metal sheet, which lowers the velocity to zero within 3.5 milliseconds. However, the necessary elongation at break for carbon fibers at a velocity of 7 m/s is reached within 400 µs, so that the targeted velocity at breakage is still 7 m/s.

Besides, increased testing speeds cause difficulties in interpreting dynamic effects of the test set-up due to resonance effects. The measured values of the load cells (Figure 5) are adversely affected by the inertia of the accelerated components and the wave propagation speed. The comparison of the two load cells mounted behind each other shows that both the stiffness and the masses can lead to significant measurement deviations during high strain rate tensile tests, since the duration for a force-equivalent deformation is not sufficient.

![Influence of testing speed on measured tensile strength](image)

**Figure 5:** Influence of testing speed on conventional loads cells for identical samples

4. Conclusion

In order to set up a tensile test system for speeds from quasi static up to 100 m/s behaving constantly across the whole speed range, it is necessary to precisely understand and measure the impact behavior until the sample breaks. For measuring forces and energies, standard load cells cause issues above 10 m/s, especially in the case of samples characterized by small breaking elongations, such as carbon and...
glass fibers. Therefore, newly combined measurement approaches have to be pursued. Since elastic impact suffers from barely predictable breaking velocity, plastic impact needs to be achieved across the whole speed range.

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References
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