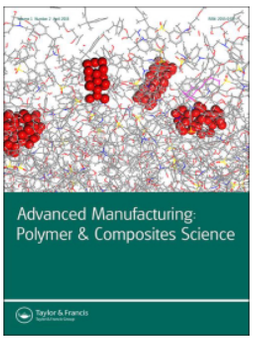

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Analysis and development of a brazing method to weld carbon fiber-reinforced poly ether ketone ketone with amorphous PEKK

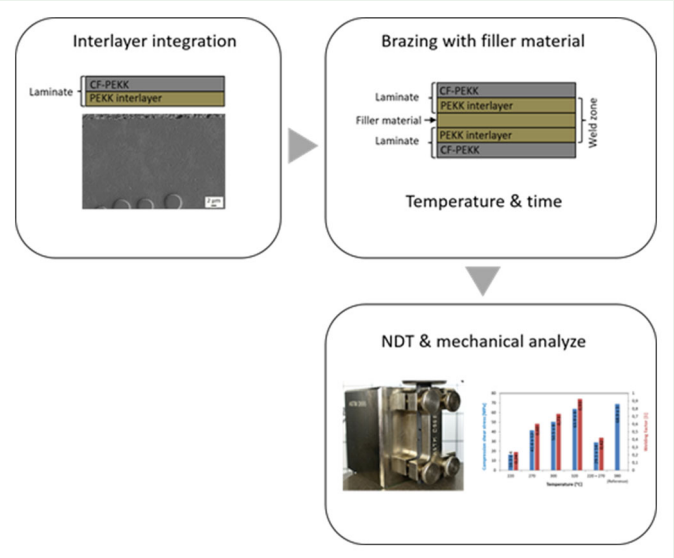
K. Kotzur[a], G. Doll[b] and P. Hermann[b]

[a]German Aerospace Center, Institute of Materials Research, Cologne, Germany; [b]German Aerospace Center, Institute of Structures and Design, Stuttgart, Germany

ABSTRACT

In this study, a brazing method for carbon fiber-reinforced poly ether ketone ketone (CF-PEKK) is developed that allows welding below the melting temperature of the single components. During the manufacturing of CF-PEKK laminates, a pseudo-amorphous PEKK film is consolidated to its surface which acts as interlayer polymer during subsequent joining (brazing). Five different brazing temperatures, determined from thermal analysis of the material, are characterized for their weld quality mechanically, analytically, and through ultrasonic testing. Microanalytically Scanning Electron Microscope (SEM) investigations focus on the morphology of the weld zone in order to evaluate the diffusion processes at the interfaces. Compared to Differential Scanning Calorimetry measurements, the SEM investigations offer a basic understanding of the welded process and its influence on the welding properties. A welding temperature of 60 °C below the processing temperature of CF-PEKK laminates (380 °C) is shown to yield a welding factor of 0.93. Furthermore, based on the SEM investigation, it is possible to derive more promising improvement measures for the brazing method.

GRAPHICAL ABSTRACT



KEYWORDS

Structural composites; interface; scanning electron microscopy (SEM); welding; joining; morphological analysis

1. Introduction

Thermoplastics offer advantages over their thermosetting counterparts such as the possibility in thermoforming and joining by fusion bonding (e.g. brazing and welding). Fusion bonding is broadly accepted as the joining of two polymer-based parts by the fusion and consolidation of their interfaces. The Thermabond® process [1], known as dual-resin or amorphous bonding, would normally be used to join large sections together, such as bonding stringers to skins [2]. The Thermabond® technique employs an interlayer polymer at the joining surface with different melting characteristics to that of the reinforced polymer in the composite. The interlayer

CONTACT G. Doll georg.doll@dlr.de German Aerospace Center, Institute of Structures and Design, Pfaffenwaldring 38-40, Stuttgart 70569, Germany.

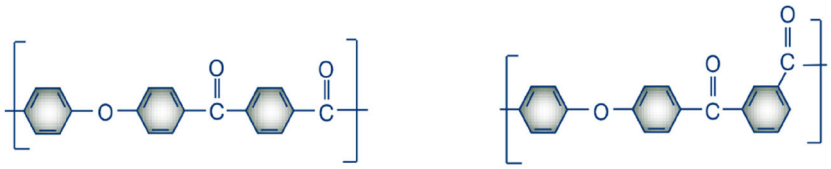


Figure 1. Chemical structure of PEKK copolymer: (left) terephthaloyl (para linkage) and (right) isophthaloyl (meta linkage).

polymer and the polymer matrix in the composite have to be compatible at the molecular level, otherwise no adhesion will be achieved between the interlayer polymer and the composite laminate during consolidation. During the joining, the components are brought together with sufficient force and the interlayer heated sufficiently above its glass transition temperature to allow it to fuse throughout, but not so high as to melt the matrix of the composite. Sufficient flow must be achieved in the interlayer to fully wet-out the surfaces, to allow for migration of entrapped air, and to facilitate molecular diffusion between the adjacent surfaces. It is also possible to combine the Thermabond® process with conventional welding methods such as resistance welding, ultrasonic welding, and co-consolidation during the oven consolidation. A well-known example of a Thermabond system is carbon fiber-reinforced poly ether ether ketone (CF-PEEK) as the composite component and amorphous poly ether imide (PEI) as the thermoplastic interlayer [1, 3, 4]. In this study, pseudo-amorphous poly ether ketone ketone (PEKK) is used as thermoplastic interlayer to weld two CF-PEKK components according to the Thermabond® process. Pseudo-amorphous PEKK is used as an alternative to PEI. The idea behind the material choice is to use material for brazing which belongs to the polymer family of poly aryl ether ketones (PAEKs) just like the matrix of the composite components. Five different brazing temperatures, determined from thermal analysis of the material, were considered. The weld quality and the welding properties for each applied process temperature are characterized mechanically, analytically, and by ultrasonic testing. Ultrasonic testing is one of the most widely used nondestructive testing (NDT) methods for structural composite materials due to its high sensitivity to various damage types commonly found in composites. Several damage types that may be generated during fabrication and/or during service can be distinguished, such as delamination, bond failure, cracking, and fiber-matrix failure [5]. It is also possible to determine a geometry of internal damage, its surface area, and depth location within composites. Furthermore, ultrasonic testing techniques are quite simple to implement for inspection. Due to these advantages ultrasonic testing is an attractive candidate when considering an industrial NDT concept. The crystalline morphology of the weld zone within brazed CFPEKK composites is analyzed spatially-resolved with Scanning Electron Microscope (SEM) and optical microscope measurements in order to evaluate diffusion processes at the interfaces. A spatially-resolved analysis of crystallinity in thermoplastic polymer or composite components has typically been performed by some form of microscopy; namely optical a, secondary electron, and transmission electron [6, 7]. Such analyses were conducted frequently between 1980 and 2000, with a primary focus on the crystalline morphology of carbon fiber-reinforced polyether ether ketone (CFPEEK) composites [8–23]. Investigations were performed to better understand the crystalline structure and crystallization mechanics of the PEEK matrix within CF-PEEK composites and, as a result, to determine the structure/property relationship perpendicular to the fiber longitudinal direction. In this study, the spatially-resolved microscopic method of assessing the crystalline morphology studies was transferred to PEKK.

2. Materials and methods

2.1. Materials

PEKK-based polymers are used for both the composite matrix and the thermoplastic interlayer. PEKK is in the family of poly aryl ether ketones (PAEK) and synthesized in various formulations with unique thermal properties. The PEKK formulations are expressed by the percentage of terephthaloyl (T) to isophthaloyl (I) moieties in the polymer chain. The terephthaloyl and isophthaloyl repeating units are illustrated on Figure 1. Varying the *T/I* ratio leads to PEKK copolymers with the melting temperature (T_m) ranging from 305 °C to 360 °C. Each configuration also features unique crystallization kinetics, though minimal variation of the glass transition temperature (T_g), ranging from 160 °C to 165 °C (Table 1). The PEKK 6000 Series represents the pseudo-amorphous products of the KEPSTAN family, offering the lowest melting point and the slowest crystallization behavior, while keeping T_g close to 160 °C. Table 2 shows the PEKK-based raw material that was used for the manufacturing and brazing of the CF-PEKK laminates.

Table 1. KEPSTANTM PEKK 6000 and KEPSTANTM PEKK 7000.

	T/*I* ratio	T_g (°C)	T_m (°C)	Morphology
PEKK 6000	60/40	160	305	Pseudo-amorphing
PEKK 7000	70/30	162	332	Semicrystalline

Table 2. KEPSTANTM PEKK 6000 and KEPSTANTM PEKK 7000.

	CF-PEKK prepreg	PEKK 6000 foil
Matrix	Kepstan™ PEKK 7002	Kepstan™ PEKK 6002
Supplier	Toho Tenax	Lite GmbH
Material name	TPUD-PEKK-HTS45 P12 12 K	Lite K62

2.2. Manufacturing of CF-PEKK laminates

For the brazing experiments, CF-PEKK laminates are consolidated by hot pressing. Therefore, a hydraulic press with electrical heated plates was used. CF-PEKK prepregs are stacked together with the sequence of [PEKK 6002/0°/90°/0°/90°/0°/90°]s. At the outer surface of the CF-PEKK laminates an amorphous PEKK 6002 foil is placed according to the Thermabond® process. The stacking sequence of the CF-PEKK reference laminates which are used for welding experiments are doubled compared to the CF-PEKK laminates, i.e. [PEKK 6002/0°/90°/0°/90°/0°/90°/90°/0°/90°/0°/90°/0°]s. A steel tool is used to consolidate the stacked CFPEKK prepregs (Figure 2). Glass fiber fabric and Kapton foil are placed between the tool and the stacked CF-PEKK prepregs. The glass fiber fabric is used to enhance migration of entrapped air within the laminate and compensate for the difference in Coefficients of Thermal Expansion between steel and the composite. The Kapton foil acts as a separation foil. The CF-PEEK laminates are heated up to 380 °C with a heating range of 10 K/min are consolidated at 380 °C with 20 bar. After that, the hot plates were cooled by air channels with a cooling rate of ca. 5 K/min.

2.3. Brazing of CF-PEKK laminates

CF-PEKK laminates are brazed according to the Thermabond® process. The hot press and tooling which are used for the consolidation of the CF-PEKK laminates are also used to braze the CF-PEKK laminates. The brazing of two CFPEKK laminates are performed with an additional PEKK 6002 foil (PEKK interlayer) in order to fill any irregularities between the adjacent surfaces (Figure 3a). The brazing process consists of three steps: heating, molecular diffusion, and cooling. The PEKK interface between the PEKK matrix of the CF-PEKK laminate and the PEKK 6002 interlayer are heated at above the glass transition temperature to a viscous state and brought together in intimate contact. The holding phase is needed in order to dissolve the PEKK-PEKK interface gradually by diffusion, i.e. by macromolecular chain migration across the interface. When macromolecule migration has bridged the interface, cooling allows the material to solidify [1, 3, 4]. As shown schematically in Figure 3b, two CF-PEKK laminates are brazed with and without subsequent annealing as well. The annealing is applied in order to induce crystallization of PEKK 6002 within the weld zone. Both, the brazing and annealing temperatures are held for a period of 10 min.

2.3.1. Definition of the process temperature

Due to the temperature dependency of polymer viscosity and molecular diffusion, different temperatures were investigated for the brazing process. A thermal analysis of PEKK 6002 foil and the CF-PEKK prepregs was conducted by means of Differential Scanning Calorimetry (DSC) to select these temperatures (Figure 4). The DSC measurements are performed in a temperature range from 20 °C to 380 °C, with heating and cooling rates of 10 K/min. These results are combined with Dynamic Mechanical Thermo Analysis (DTMA) data from Arkema [24].

Various process temperatures for brazing were chosen:

- 220 °C was chosen due to the amorphous morphology of PEKK 6002. When using 220 °C, it can be expected that the morphology of the joining zone remains amorphous after brazing.
- Amorphous thermoplastics exhibit poorer mechanical properties and medium stability as semicrystalline thermoplastics. Therefore, CF-PEKK laminates which are brazed at 220 °C, are additionally annealed at 270 °C in order to induce cold crystallization.
- 270 °C was chosen due to the strongly increased amount of crystalline phase induced by cold crystallization. It can be expected that the morphology of the joining zone remains semicrystalline after brazing at 270 °C.
- At 300 °C, the amount of induced crystalline phases is partly decreased by melting. Thus, the amount of crystalline phases is less compared to the brazing temperature of 270 °C and greater than the brazing temperature of 220 °C. It can be expected that the morphology of the joining zone remains semicrystalline after brazing at 300 °C.
- 320 °C was chosen due to the amorphous morphology of PEKK. Compared to the brazing temperature of 220 °C the viscosity of PEKK is much lower. Moreover, increased mobility of molecule chains leads to enhanced molecular diffusion through the adjacent PEKK interfaces. It can be expected that the morphology of the joining zone remains amorphous after brazing at 320 °C.

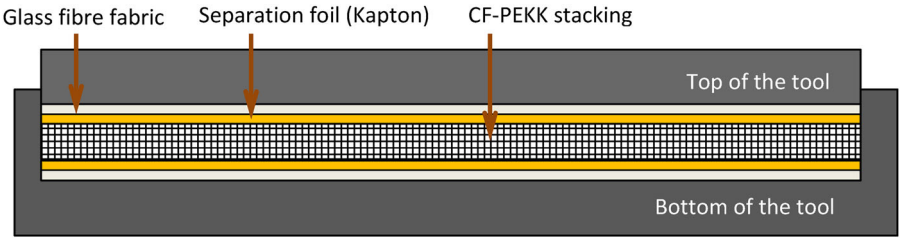


Figure 2. Setup used for consolidation of CF-PEKK laminates by hot pressing.

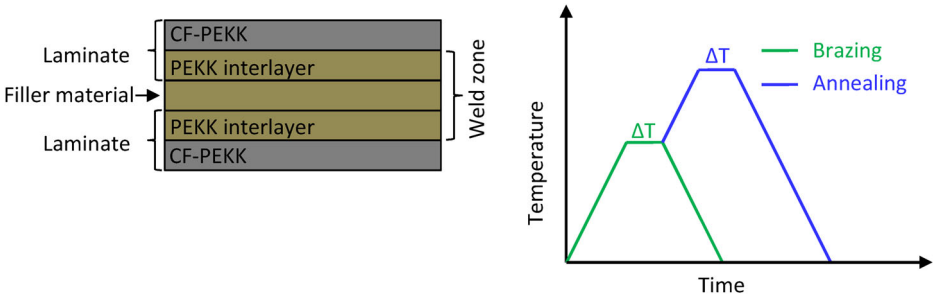


Figure 3. Brazing of CF-PEKK laminates with PEKK according to the Thermabond® process: (left) layer structure and (right) time temperature prole.

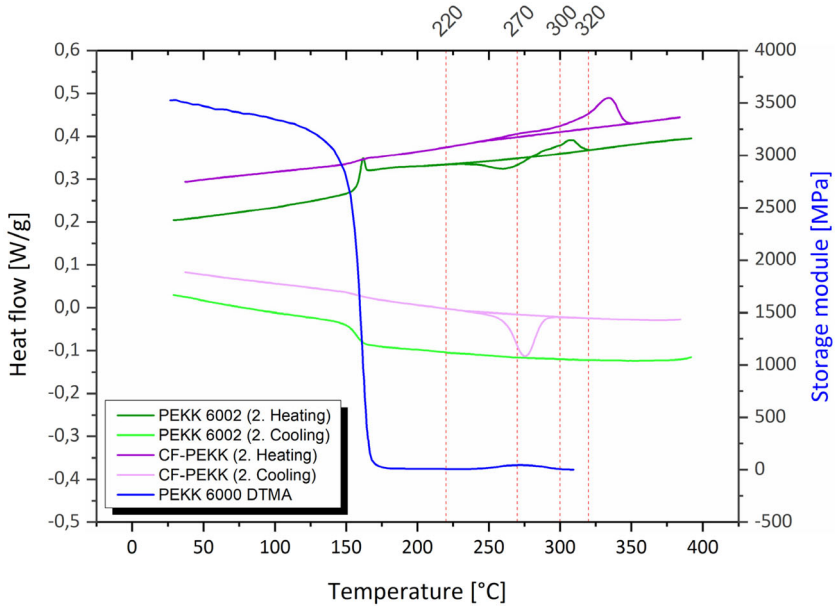


Figure 4. DSC heating and cooling curves of neat PEKK6002 and CF-PEKK prepreg. DTMA data originates from Arkema.

2.4. Material characterization

Different methods were used to characterize to quality of the weld zone. First of all, NDT will be used to detect defect free regions. The sampling position for cutting which is supposed for microscopic investigation and mechanical characterization was chosen based on these results.

2.4.1. Nondestructive testing

The ultrasonic Pulse-Echo technique is used to evaluate weld quality at the interface within the welded CF-PEKK laminates. Thereby, ultrasonic waves are coupled from a transducer into the laminate at one surface. The waves propagate through the laminate and reflect either at internal interfaces and by internal flaws/defects or by the rear surface. The analysis of the weld quality is based on the observation of the reflected ultrasonic waves which are received by the same transducer. In this study, a 5L64-NW1 multi-element transducer connected to an Olympus Omniscan MX2 is used as source and receiver. The induced waves have a velocity ranging from 2600 to 5300 m s^{-1} and a frequency of 5 MHz. The quality of the laminates after manufacturing and the weld quality of laminates after welding are evaluated nondestructively through ultrasonic C-scan technique. The C-scan is a two-dimensional map which represents flaws in the plan view. C-scans are obtained by extracting the information from B-scans. B-scans are

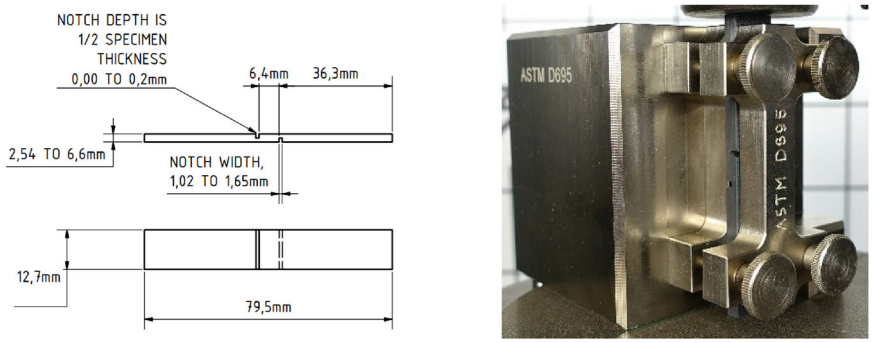


Figure 5. Compression shear test according to ASTM D 3846: (left) specimen geometry and (right) experimental setup.

two-dimensional maps which reflects the cross-section of the tested laminates. The transducer scans the laminates in a grid pattern.

2.4.2. Morphological investigation

The crystalline morphology of the PEKK interlayer and their interface to CF-PEKK are analyzed by optical microscope and SEM. Therefore, cross-sections are prepared metallographically and subsequently etched by ion beam etching (Gatan MET-ETCH Model 683). Five short etching sequences of 15 min were conducted to prevent the ion beam from changing the morphology due to heat. The parameter settings used are 3 keV, a tilt angle of 45°, and a rotation speed of 20–30 rpm. During the etching, the ion beam removes material from the surface of the cross-section. The binding energy of the molecular structure is higher in the case of crystalline regions like spherulites. Thus, the ablation rate of crystalline regions is lower compared to amorphous regions. The resulting height profile of the ion-etched surface can be observed with the secondary electron detector of the SEM.

2.4.3. Mechanical investigation

The welding properties of each brazing temperature are determined by quasi-static compression shear test according to the standard ASTM D 3846 (Figure 5). The samples are prepared by means of a diamond blade saw including the notch. For the testing, a ZWICK Roell Pro Line 1475 with 10 kN force sensor is used. The applied testing speed is 1.3 mm/min according to the standard. The welding quality was evaluated with the help of compression shear specimens which originates from manufactured reference CF-PEKK laminates. The reference specimens are known for the interface properties of an ideal CF-PEKK joint. For comparability, 10 samples per configuration were taken from the plates. The position was determined with the help of ultrasound scans to produce a representative result.

The welding factor will be determined in order to enable comparison between the five process temperatures applied in this study. Moreover, the welding factor even allows a comparison with other welding methods. It describes the bonding strength of brazed specimen σ_W in relation to that of the reference specimen σ_R. Thus, the equation of the welding factor is defined as follows

$$n = \frac{\sigma_W}{\sigma_R} \tag{1}$$

3. Results

3.1. Manufactured CF-PEKK laminates

3.1.1. Surface roughness

During the consolidation of the CF-PEKK laminates, the prepregs are in the molten state and pressed into the glass fiber fabric. As a result, the CF-PEKK laminates offer at their surface the same roughness as the glass fiber fabric, shown on the fracture surfaces (Figure 12).

3.1.2. Morphology of the PEKK 6002 interlayer and its interface to CF-PEKK

During the consolidation of the CF-PEKK laminates, two mechanisms can contribute to the adhesion between the CF-PEKK prepregs and the PEKK interlayer. These mechanisms include fiber migration (i.e. the migration of the reinforcing fibers of CF-PEKK into the interlayer region) and PEKK miscibility. Migration of carbon fibers was observed for the samples produced (Figure 6b). PEKK 7002 and PEKK 6002 are firmly jointed to each other, though the PEKK interlayer region shows two characteristic morphologies. The PEKK interlayer mostly consists of a crystalline morphology (Figure 6c). Crystalline phases of the interlayer are not desired due to the increase of the melting temperature of PEKK. The PEKK interlayer also shows a two-phase morphology, i.e. spherulites which are embedded in an amorphous PEKK matrix (Figure 6d). The two phase morphology provides amorphous regions at the outermost surface. From DSC analysis, it is known that PEKK 6002 remains amorphous during cooling from 380 °C to 20 °C. Thus, it is unlikely

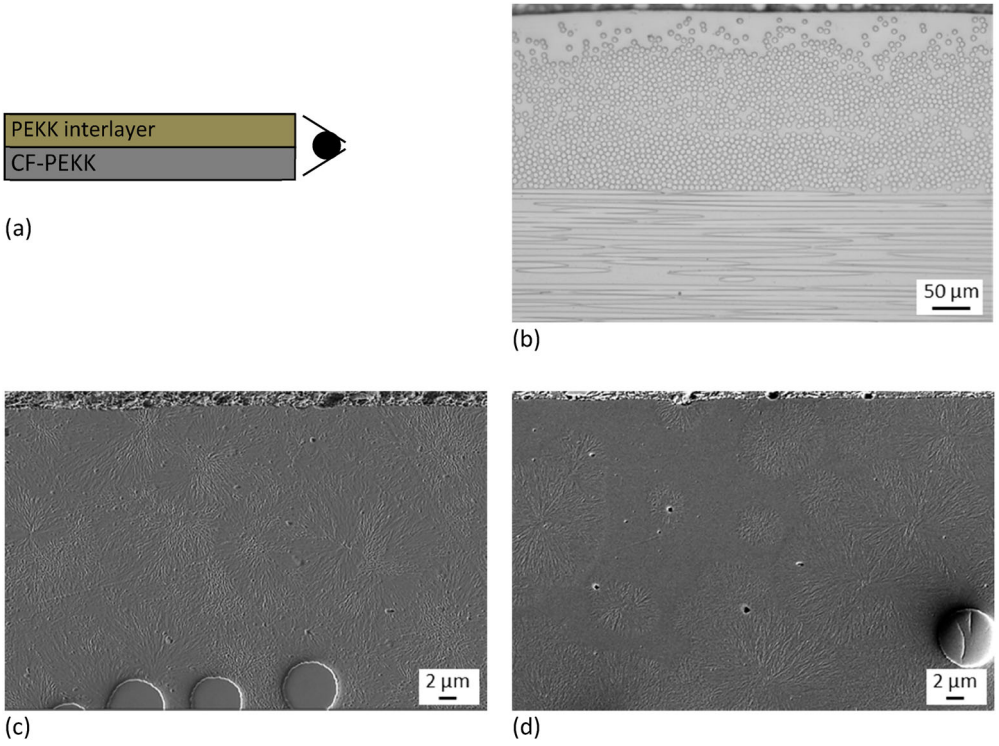


Figure 6. Surface zone of manufactured CF-PEKK laminates: (a) viewing direction, (b) optical microscopic image, and (c, d) SEM images of crystalline morphology.

that the crystalline phases originate from the PEKK 6002 foil. It is more likely that the crystalline phases originate from PEKK 7002 resin of the CF-PEKK prepregs. The polymer miscibility is a measure of the molecular compatibility. Due to almost equal chemical structure of PEKK 6002 and PEKK 7002, a good blending of both PEKK types can be expected. During the consolidation of CFPEKK laminates, PEKK 7002 including their nuclei can diffuse through the interface to PEKK 6002. As a result, the diffused nuclei of PEKK 7002 within PEKK 6002 enable crystallization within the interlayer region.

3.2. Brazed CF-PEEK laminates

3.2.1. Bond quality of the interface by ultrasonic inspection

Ultrasonic C-scan technique reveals that manufactured CF-PEKK laminates are defect-free. This does not apply to welded laminates. When comparing laminates before and after welding, it can be concluded that detected flaws are located within the welding zone between two welded laminates. These flaws indicate insufficient weld quality. The color amplitude response describes the bond quality of each pixel within the scan, as well as the corresponding color scale of the amplitude response. Figure 7b,c shows the C-scans of the CF-PEKK laminates which are brazed at 300 °C and 320 °C. The C-scan of the laminate brazed at 320 °C shows no significant weld defects. The C-scan of the laminate brazed at temperature below 300 °C looks different from that. The laminate indicates sufficient weld quality in the center but insufficient weld quality at the edges of the laminate. This could be the result of an inhomogeneous temperature and pressure distribution during brazing.

Based on the C-scan, it can be assumed that the melt flows from the middle to the edge of the laminate. Thereby, interfacial air can be pressed out of the laminate. The side view of the CF-PEKK laminates (Figure 8) clearly shows a lower melt flow in the case of the laminate which is brazed at 300 °C. This result is in a good agreement with the ultrasonic C-scans.

3.2.2. Bond quality of the interface by optical microscopy inspection

The bond quality at the interface of the CF-PEKK laminates is analyzed by optical microscopy. For sampling, defect-free regions are chosen on the basis of the ultrasonic C-scans. Regardless of the temperature used for brazing, prepared cross-sections show regions with and without firm bonding (Figure 9). Increased brazing temperature leads to better bonding, e.g. to more regions which seem to be bonded firmly. The analysis of the bond quality by optical microscopy and by ultrasonic testing leads to similar results.

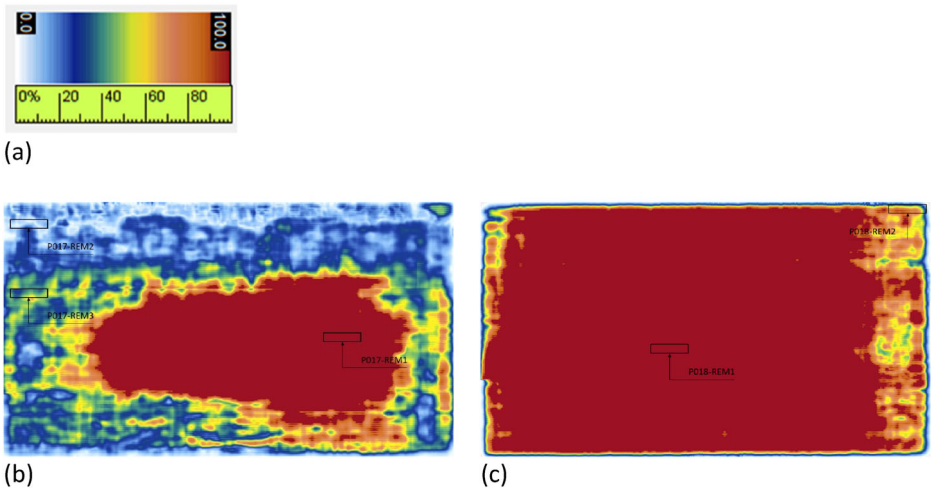


Figure 7. Ultrasonic C-scans of CF-PEKK laminates: (a) amplitude response and (b) C-scan of the laminate brazed at 300 °C and (c) at 320 °C.

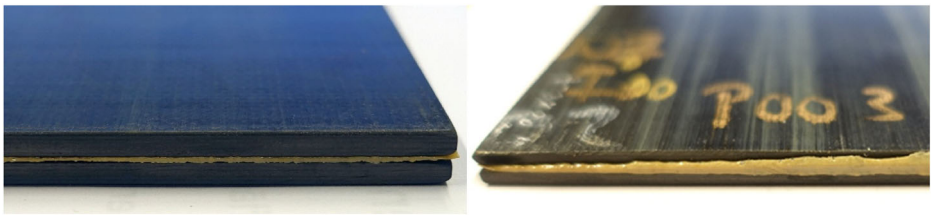


Figure 8. Side view of CF-PEKK laminates which are brazed at (left) 300 °C and (right) 320 °C show the dependency of the melt flow on the temperature.

Moreover, the resulting thickness of the PEKK interlayer between two CF-PEKK laminates is thinner when using 320 °C for brazing. This can be attributed to the lower melt viscosity of PEKK at 320 °C which affects various mechanisms at the PEKK interface during brazing. Carbon fibers of the CF-PEKK laminate migrate through the interface to PEKK 6002 interlayer. The PEKK matrix (including their nuclei) and the PEKK 6002 interlayer diffuse through each other through their interface. Additionally, more PEKK within the joining zone flows out of the laminate due to the increased melt flow of PEKK at 320 °C. Based on the analysis of the joining zone by optical microscopy, better mechanical interface properties can be expected if the laminates are brazed at 320 °C.

3.2.3. Morphology of the interface

The specimens which are already used for the analysis with the optical microscope are also used for the analysis of the crystalline morphology of the interface. The PEKK 6002 interlayer at the PEKK interface remains crystalline during cooling when using 300 °C for brazing (Figure 10b). The PEKK 6002 interlayer remains amorphous when using 320 °C for brazing (Figure 10c,d). This result is consistent with the DSC analysis. SEM images taken from regions which seem to be firmly bonded under the optical microscope do not always show firm bonding. No complete weld zone is developed. At brazing temperatures less or equal 300 °C CF-PEKK laminates are not bonded firmly with the PEKK interlayer which acts as filler material (Figure 10b). The brazing temperatures are chosen according to the characteristic temperature range of amorphous PEKK 6002. From the morphological analysis of the PEKK interlayer region, it is known that it exhibits either a crystalline or two-phase morphology. Therefore, the chosen temperature could be too low for the bonding by brazing. The CF-PEKK laminates which are brazed at 320 °C partially show a firmly substance-to-substance bond between the amorphous PEKK interlayer (filler material) and the crystalline PEKK interlayer of the CF-PEKK laminate (Figure 10c,d).

This result makes clear that the analysis of the bonding quality needs additional reliable analyzing techniques such as morphological analysis by using a secondary electron microscope. However, ultrasonic C-scan technique combined with optical microscopic analysis is not adequate to evaluate the bonding quality.

3.2.4. Compression shear test

The shear strength increases with increasing brazing temperature from 220 °C to 320 °C as shown in Figure 11. The highest welding strength could be achieved at 320 °C. The weld strength corresponds to

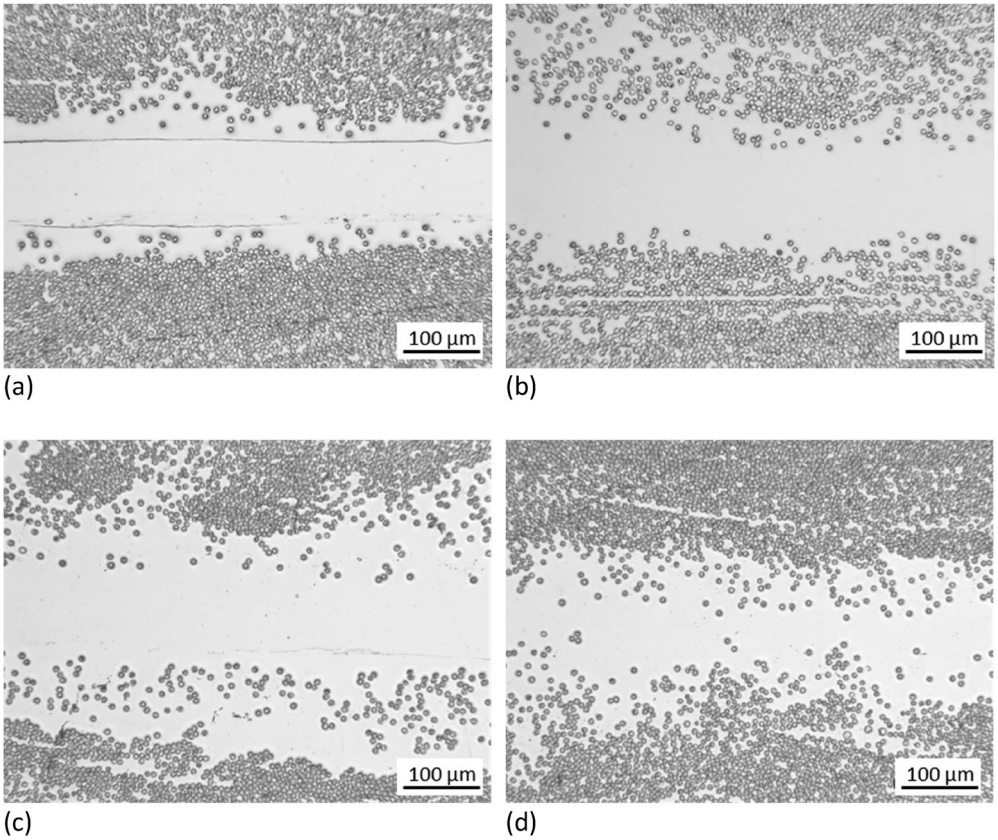


Figure 9. Optical microscope images show the joining zone: (a) no bonding at 300 °C, (b) bonding at 300 °C, (c) almost finished bonding at 320 °C, and (d) bonding at 320 °C.

a welding factor of 0.93. The results are in good agreement with the results obtained by microscopic analysis.

The surface roughness of the CFPEKK laminates which is induced by the glass fiber fabric during their consolidation is still visible at the fracture surface with the naked eye (Figure 12). The amount of roughening at the fracture surface decreases with increasing brazing temperature. This tendency is consistent with the results of the compression shear testing, i.e. the lower the amount of remaining surface roughness the higher the compression shear strength. This result indicates insufficient softening of the CF-PEKK laminate during brazing due to insufficient process temperature. The morphological analysis of the CF-PEKK laminate, i.e. the crystalline phases within the PEKK interlayer region, provides an explanation for this result. The fracture surface of the reference specimens shows the ideal failure mode, i.e. an interlaminar shear failure which is located outside of the joining zone (Figure 13b). This indicates a strong welding within the joining zone. The fracture surface of specimens which are brazed at temperatures less or equal 300 °C shows adhesive failure between the CF-PEKK laminate and the PEKK interlayer (Figure 12). The same failure mode can be observed at the fracture surface of the specimens which are brazed at 220 °C and subsequently annealed at 270 °C. Adhesive failure indicates insufficient molecular diffusion at the interface between the PEKK 6002 interlayer and the PEKK interlayer region of the CF-PEKK laminate.

The fracture surface of the specimens brazed at 320 °C shows different failure modes as shown in Figure 13a. The failure mode includes adhesive-cohesive failure which occur within the joining zone and interlaminar shear failure which is located outside of the joining zone. Cohesive and interlaminar shear failure indicates a stronger bonding of the interface between the PEKK interlayer and the PEKK interlayer region of the CF-PEKK laminate.

4. Discussion

In this study, a brazing method for CF-PEKK components is developed that allows welding below the melting temperature of the single components. Different analyzing methods are applied in order to gain a deep process understanding. The ultrasonic C-scans of the brazed CF-PEKK laminates are in good agreement with the results of the optical microscopy. However, the results of the optical microscopy are not in good agreement with the secondary electron microscopy. The CF-PEKK/PEKK interface which seems to be bonded firmly under the optical microscope and ultrasonic C-scan shows

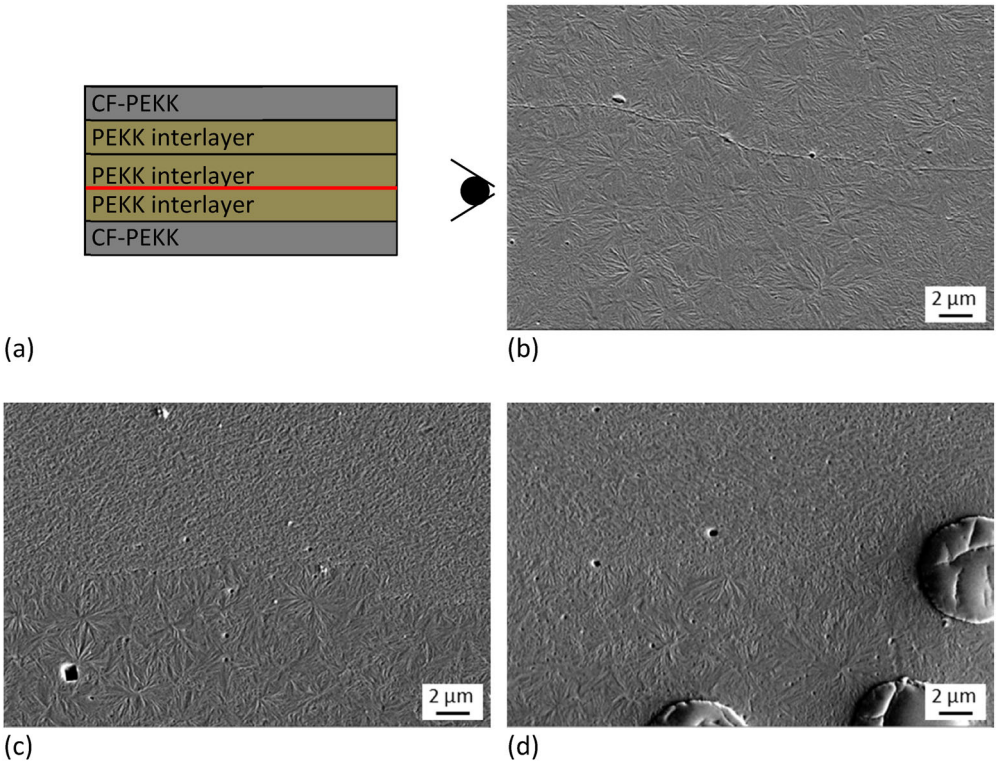


Figure 10. SEM images show the joining zone: (a) viewing direction and joining zone obtained at (b) 300 °C as well at (c, d) 320 °C.

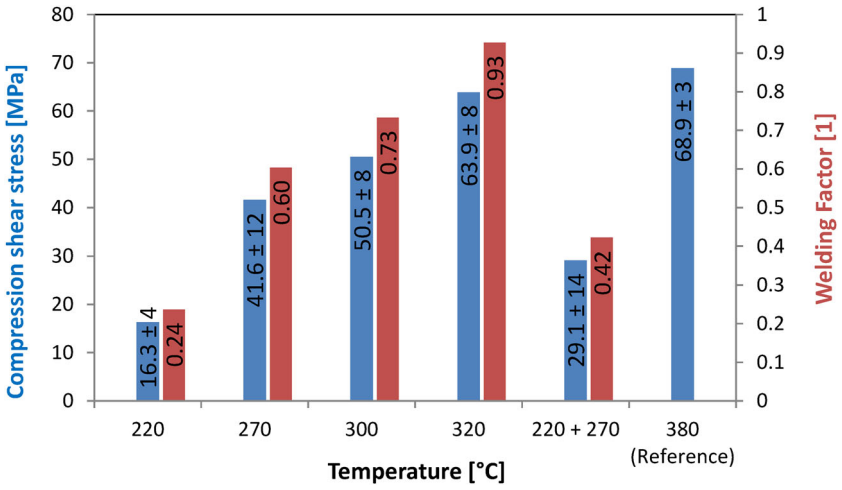


Figure 11. Compression shear strength including standard deviation of CF-PEKK bonded by brazing.

insufficient bonding under the SEM. The analysis of the crystalline morphology of thermoplastic PEKK which are performed locally with SEM provides the most useful understanding of the whole brazing process. Compared to DSC measurements it provides locally resolved information of the crystalline morphology. The analysis of the crystalline morphology clearly shows that the PEKK 6002 interlayer region does not remain amorphous during the consolidation of CF-PEKK laminates. Quite the contrary, the PEKK interlayer consists of both a crystalline and two-phase morphology. The process temperatures are chosen on the characteristic temperatures of amorphous PEKK. Therefore, the chosen temperatures for brazing are too low for molecular diffusion at the interface between the CF-PEKK laminate and the PEKK interlayer (filler material). However, there are enough amorphous regions within the two-phase morphology of the PEKK interlayer which allows successful brazing at a temperature of 320 °C which is 60 °C below the processing temperature of CF-PEKK laminates. Thereby, a welding factor of 0.93 can be obtained. The microscopic analysis clearly shows an inhomogeneous bond quality and several areas which are not bonded. This can be traced to both the surface roughness of the CF-PEKK laminates and the insufficient process temperature used for brazing. The

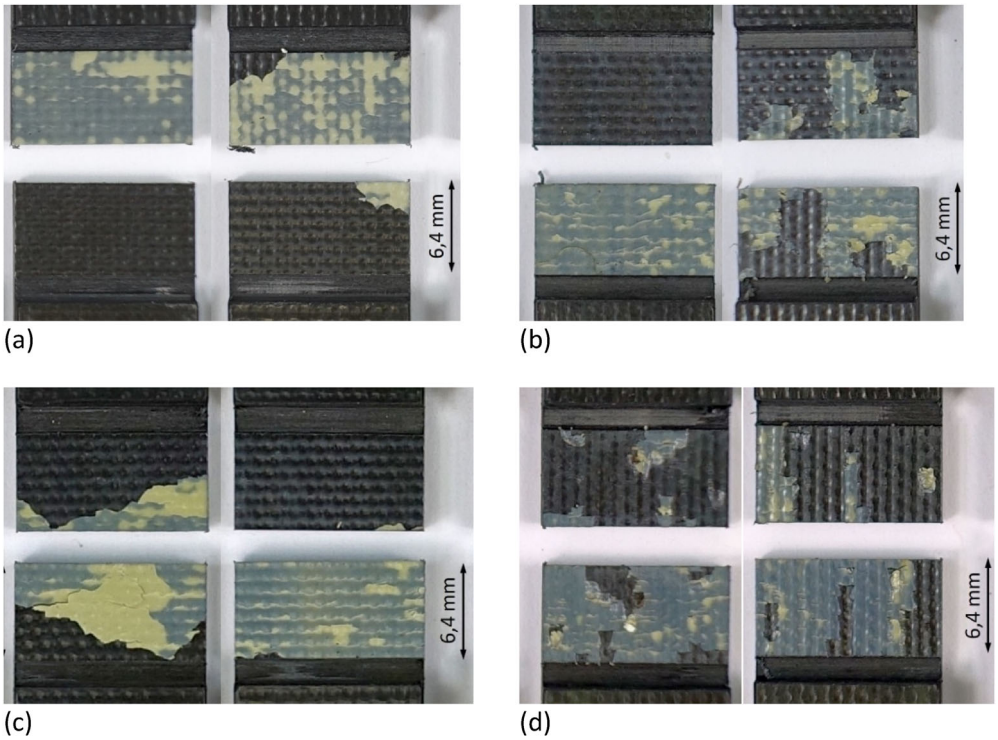


Figure 12. Fracture surface of tested compression shear specimens brazed at (a) 200 °C, (b) 270 °C, (c) 220 °C including annealing at 270 °C, and (d) 300 °C.

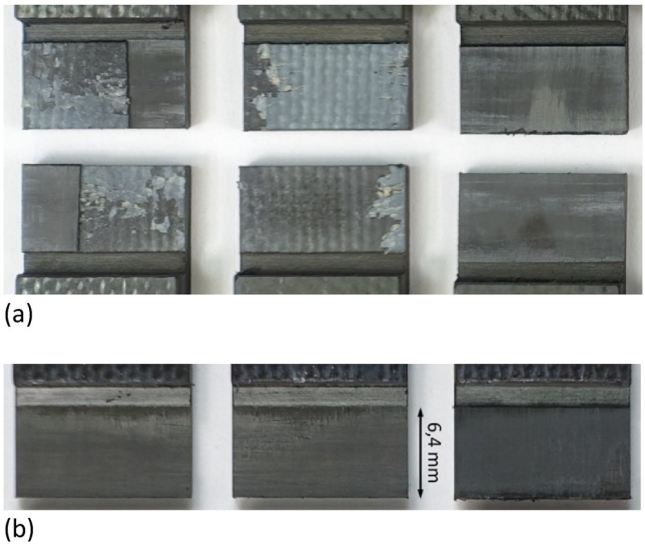


Figure 13. Fracture surface of tested compression shear specimens brazed at (a) 320 °C and (b) reference specimens with ideal bonding properties.

surface roughness which are induced by the consolidation of the CF-PEKK laminates leads to reduced intimate contact at the interface between the CF-PEKK laminate and the PEKK 6002 interlayer. Sufficient intimate contact requires softening of the surfaces in the case of roughened surfaces. The softening of the adjacent surfaces during brazing in turn requires sufficient process temperature. The remaining roughness of the fracture surfaces indicates insufficient softening and thus insufficient intimate contact due to insufficient process temperature which are chosen for brazing.

5. Conclusions and outlook

The analysis of the crystalline morphology which is used the first time in the field of fusion bonding of thermoplastic composites provides the most useful process understanding. The consolidation of CF-PEKK with an integrated PEKK interlayer at its surface as produced in this study leads to an undesired result. The resulting blending between the PEKK interlayer and the CF-PEKK prepregs has to be suppressed during the consolidation of the laminate. When creating an amorphous PEKK interlayer at the surface of CF-PEKK laminates the process

window can be significantly shifted to lower brazing temperature. Based on this result, promising improvement measures can be derived to significantly improve the brazing process.

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Disclosure statement

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ORCID

G. Doll http://orcid.org/0000-0002-5961-6593

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