Chapter 5

Development of sterilized Antheraea Assama (AASF) /polypropylene (PP) based suture biomaterial*

5.1 Introduction
In this chapter, low temperature plasma grafting of polypropylene (PP) onto sterilized Antheraea assama silk fibroin (AASF) and the characterization of PP grafted AASF (PP-AASF) as suture biomaterial is discussed in details. In earlier works, surface treatment using Ar plasma and grafting of PP using Ar/propylene plasma was carried out to improve the mechanical strength and water contact angle of AASF. Currently, there is no report on detailed studies on the surface modification of AASF using low temperature plasma treatment/graft polymerization for investigating its utility as suture biomaterial. PP is an excellent biomaterial that has received significant importance as hernia repair, wound dressing, surgical suture, bio-composites and blood transfusion bags [1-8]. As surgical suture, PP exhibits high tensile strength and durability, minimal tissue drag, least thrombogenicity and tissue reactivity among all currently available sutures, good resistance to bacterial contamination and flexural fatigue, no degradation by tissue enzymes, inertness to living tissue and low water uptake behavior [9-16]. However, low knot security, high plasticity, slippery handling characteristics and use of artificial color for high visibility are some of the limitation of PP suture that hinders its efficient utilization in surgical process [17-32]. Considering the remarkable properties of AASF as well as the suture characteristics of PP, there is a good likelihood of developing an advanced suture biomaterial by grafting PP onto AASF that may exhibit


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relatively superior physical and mechanical properties and antibacterial activity than the formers. The prime objective of this work is to evaluate the potential of PP-AASF as suture biomaterial, with an aim to meet most of the essential requirement of an ideal suture. To accomplish this goal, AASF is first sterilized using Ar plasma treatment followed by grafting of PP onto its surface using Ar/propylene plasma discharge. The various characterizations of PP-AASF are carried out in details and the results are correlated with that of AASF and Ar plasma treated AASF for better comparison.

5.2 Raman spectroscopy of the developed (PP-AASF), AASF_{Ar} and AASF suture material

The Raman spectra of AASF, AASF_{Ar} and PP-AASF, measured in the spectral region (2500-750 cm^{-1}) of interest, are shown in Figures 5.1 (a)-(c). The peaks at 2405 and 2108 cm^{-1} represent characteristic α-helical and β-sheet conformation of AASF [33]. Besides, the spectral patterns are further characterized by the peaks at 1665 (amide I), 1234 (amide III) and 1083 cm^{-1} which are assigned to β-sheet conformation whereas the peaks at 1058, 945 and 906 cm^{-1} arise from α-helical conformation of fibroin region containing polypeptide (poly(-Gly-Ala) chain) sequences [34-40]. From Figures 5.1 (a)-(c), it appears that position and intensity of the peaks characteristics of β-sheet AASF remain essentially unchanged. This may suggest that plasma treatment and grafting take place in the amorphous region of AASF. On the other hand, Ar plasma treatment and grafting of PP seem to influence the fibroin conformational transition of AASF. From Figures 5.1 (a)-(c), it is revealed that as AASF is treated in Ar plasma and subsequently grafted with PP, the intensity of the peak at 2405 cm^{-1} progressively decreases while a new peak appears at 2108 cm^{-1} that can be attributed to β-sheet conformation of AASF. This finding indicates that the poly (-Gly-Ala) chain of SF region undergoes an α-helical→β-sheet conformation transition when PP is grafted onto AASF_{Ar}. The α-helical→β-sheet conformation transition in AASF_{Ar} and PP-AASF is further revealed from the following observations:

(a) The position of the peak (1058 cm^{-1}) that is observed in the Raman spectrum of AASF shifts towards higher wavenumber at 1078 and 1083 cm^{-1} for AASF_{Ar} and PP-AASF respectively that are assigned to β -sheet conformation of poly((-Gly-Ala) chain.
(b) The peak at 945 cm\(^{-1}\) that is observed in the Raman spectra of AASF and AASF\(_{Ar}\), disappears in the spectrum of PP-AASF.

(c) The intensity of the peak at 906 cm\(^{-1}\) gradually decreases in the spectra of AASF\(_{Ar}\) and PP-AASF.

**Figure 5.1:** FT-Raman spectra of (a) AASF, (b) AASF\(_{Ar}\) and (c) PP-AASF collected in the spectral region (2500-750 cm\(^{-1}\)) of interest.

From Raman spectra presented in Figures 5.1 (a) and (b), it appears that the peak at 1246 cm\(^{-1}\) that corresponds to amorphous random coil conformation shifts towards lower wavenumber (1242 cm\(^{-1}\)) [41-43]. However, in the Raman spectrum of PP-AASF, the intensity of the peak is observed to be increased and the peak further shifts towards lower wavenumber (1234 cm\(^{-1}\)) that corresponds to \(\beta\) -sheet conformation [41-43]. From this finding, it is apparent that plasma grafting of PP onto AASF\(_{Ar}\) leads to random coil\(\rightarrow\) \(\beta\) -sheet conformation transition that enhances semi-crystalline nature of PP-AASF as compared to AASF and AASF\(_{Ar}\). The Raman peaks at 1166 cm\(^{-1}\) is attributed to the combination of C-C stretching and C-OH bending vibration whereas that at 1009 cm\(^{-1}\) is associated with skeletal C-C stretching vibration of random coil
conformation of AASF [44]. No change in intensity and position of the peaks can be observed in the Raman spectrum of AASF\textsubscript{Ar}. However, as observed from Figure 5.1 (c), both the peaks shift towards higher wavenumber (1171 and 1012 cm\(^{-1}\) respectively) thereby indicating that the presence of grafted PP in the amorphous regions of AASF\textsubscript{Ar} might have influenced the vibrational modes of the fibroin chains. The grafted PP may chemically resemble to isotactic PP (i-PP) as revealed by the Raman peaks at 1443 (CH\(_2\) bending mode), 1152 (C-C stretching/CH bending mode) and 994 (CH\(_3\) rocking mode) cm\(^{-1}\) that represent the crystalline state of i-PP [45]. Besides, the appearance of two new peaks at 840 (CH\(_2\) rocking mode, C-C stretching mode) and 805 cm\(^{-1}\)(CH\(_2\) rocking mode) in the Raman spectrum of PP-AASF, that are also the characteristic of i-PP, may further support the above inference [45]. As observed from Figure 5.1 (c), the higher intensity of the peak at 1443 cm\(^{-1}\) can be attributed to the contribution of the CH\(_2\) bending mode of both grafted PP and AASF [46]. The peak at 854 cm\(^{-1}\) indicates the presence of tyrosine residues in AASF [47]. The intensity of the peak is sensitive to the environment in the tyrosine side-chain and in particular to the nature of the hydrogen bonding of the phenyl hydroxyl group [48]. Gradual lowering in intensity of the peak, as observed in the Raman spectra of AASF\textsubscript{Ar} and PP-AASF, suggest that during Ar plasma treatment and subsequent grafting of PP onto AASF\textsubscript{Ar}, tyrosine residues with polar groups change their state from hydrophilic to hydrophobic environment where they are involved in weak hydrogen bonds. As most of the tyrosine residues exist in the amorphous polypeptide chains of SF region, this change of environment can be associated with the \(\alpha\)-helical\(\rightarrow\)\(\beta\)-sheet conformation transition in AASF\textsubscript{Ar} and PP-AASF [48-50].

5.3 WAXD analysis

Figure 5.2 shows the WAXD curves of AASF, AASF\textsubscript{Ar} and PP-AASF plotted within the diffraction angle (2\(\theta\)) range of 10\(^{0}\)\(-40^{0}\). Two main peaks are observed in the WAXD curves of the samples at around 2\(\theta\)= 16.5\(^{0}\) and 20.2\(^{0}\). These two peaks are the characteristics of AASF and correspond to highly ordered antiparallel \(\beta\)-sheet crystalline structure of poly(-Gly-Ala) chain [51]. The appearance of a peak at 33.8\(^{0}\) is attributed to parallel \(\beta\)-sheet crystalline region in poly(-Gly-Ala) chain with relatively less ordered structure than antiparallel \(\beta\)-sheet due to the hydrogen bonds not being
optimal alignment [52-53]. The minor peaks (2θ = 14.8°, 24.2°, 26.5°, 28.4° and 30°) of the diffraction curves of the samples characterize calcium oxalate (CaC$_2$O$_4$) crystal which is generally left by the silkworm during spinning process (excrement).

**Figure 5.2:** X-ray diffraction patterns of AASF, AASF$_{Ar}$ and PP-AASF in the diffraction range of 10°-40°.

From Figure 5.2, it is observed that the positions of the peaks present in the WAXD curves of the samples remain unchanged while the intensities of the peaks around 2θ = 16.5° and 20.2° increases with Ar plasma treatment and subsequent grafting of PP onto AASF$_{Ar}$. To gain more insight into the crystalline structure of AASF, AASF$_{Ar}$ and PP-AASF, the FWHM and crystallite size are calculated corresponding to the diffraction peaks around 2θ = 16.5° and 20.2° and presented in Table 2. From the data presented in Table 5.1, it is apparent that Ar plasma treatment and grafting of PP enhances the crystallinity and crystallite size of PP-AASF. This most likely happens due to the transition from the amorphous (α-helical and/or random coil) to the crystalline (β-sheet) state during Ar plasma treatment and plasma grafting of PP onto AASF$_{Ar}$ as a result of molecular re-arrangement of the fibroin region of poly(-Gly-Ala) chain, apparently induced by energetic ions impinging at the substrates. This finding may find good agreement with the results obtained from Raman spectroscopy analysis. The crystallite size of each of the samples is calculated using the well known Scherrer equation.
where $\beta_{1/2}$ is the value of full width half maxima (FWHM), $\lambda$ is the wavelength of the X-ray beam and $\theta$ is the angular position of Bragg’s peak (in degree).

### Table 5.1 Calculated values of FWHM and crystallite size of AASF, AASF$_{Ar}$ and PP-AASF from XRD pattern.

<table>
<thead>
<tr>
<th>Sample</th>
<th>FWHM ($^\circ$)</th>
<th>Crystal size (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak position</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16.5$^\circ$</td>
<td>20.2$^\circ$</td>
</tr>
<tr>
<td>AASF</td>
<td>2.78</td>
<td>1.89</td>
</tr>
<tr>
<td>AASF$_{Ar}$</td>
<td>2.31</td>
<td>1.63</td>
</tr>
<tr>
<td>PP-AASF</td>
<td>2.13</td>
<td>1.52</td>
</tr>
</tbody>
</table>

### 5.4 Surface morphology

Figures 5.3 (a)-(c) show the typical FESEM images of AASF, AASF$_{Ar}$ and PP-AASF. Figure 5.3 (a) reveals the presence of residual sericin at the surface of AASF. Because the general degumming process in which silk fibres are boiled in sodium carbonate solution to dissolve the sericine is not 100% efficient. Due to which the innermost layer of the gum still remained on the fibre surface and degrades the fibre properties. The white crystals observed from Figures 5.3 (a)-(c) are attributed to calcium oxalate (CaC$_2$O$_4$) and are generally left by the silkworm during spinning process (excrement). Presence of these materials are the major reasons to limits the actual benefits of natural silk for various biomedical applications. As revealed from Figure 5.3 (b), Ar plasma treatment leads to almost complete removal of residual sericin present on the surface of AASF. This is apparently caused by plasma sputtering effect, in which energetic ion bombardment on the surface of AASF possibly results in breakage of peptide bond and side chain groups of amino acid, mainly glycine and serine, which are the major constituents of sericin and efficiently in removing the weakly bonded (H-bond) regions on the fibroin surface [56, 57]. Similar observation has already been made in case of UV/ozone-irradiated Bombyx mori silk fibroin. The breakage of the amino acid groups and peptide chain scission may contribute to the removal of loosely bonded fibroin region through the formation of various volatile products (CO, OH, CO$_2$ etc.), which
subsequently lead to a decrease in oxygen and nitrogen contents in the fibres. The ion bombardment energy may further contribute to the surface roughness of AASF\textsubscript{Ar} in the form of micro-pits and cracks as observed from Figure 5.3 (b). However, plasma grafting of PP onto AASF\textsubscript{Ar} results in relatively smooth surface morphology (Figure 5.3 (c)) as compared to AASF and AASF\textsubscript{Ar}. This may be accounted for uniform grafting of micro-roughness structured PP onto AASF\textsubscript{Ar}. It is obvious that the micro-roughness of PP-AASF surface is due to the PP homopolymer oligomers adhering on the surface of AASF\textsubscript{Ar} during plasma grafting process and/or impinging ion energy to the surface of the substrate.
5.5 Physical properties

5.5.1 Knot strength and water contact angle

The data on knot strength and elongation at break of AASF, AASF$_{Ar}$ and PP-AASF are presented in Figure 5.4. It is observed from Figure 5.4 that Ar plasma treatment on AASF does not seem to affect the knot strength although the elongation at break increases in AASF$_{Ar}$. On the other hand, plasma grafting of PP onto AASF$_{Ar}$ results in considerable increase in both knot strength and elongation at break of PP-AASF. It is apparent that plasma grafting of PP with micro roughness surface structure provides uniform interlocking among the fibres and this leads to the increased friction between fibre to fibre and hence yarn to yarn knot strength. Moreover, an increase in semi-crystalline structure due to $\alpha$-helical/random coil $\rightarrow$ $\beta$-sheet conformation transition may also enhance the observed mechanical properties of PP-AASF over that of AASF and AASF$_{Ar}$. For good healing process the capillary activity of the suture material must be low because of that water contact angle measurement is carried out for all the samples (AASF, AASF$_{Ar}$ and PP-AASF). It is observed from the Table 5.2, the dynamic contact angle of AASF is found to be increased after Ar plasma treatment. This is due to
the removal of residual sericine gum and the attachment fibroin with the polar component of the sericine after energetic ion bombardment on the fibre surface.

**Figure 5.4:** Variation in the knot strength and elongation at break of AASF, AASF$_{Ar}$ and PP-AASF. Data are reported as mean ± standard error (S.E.) of mechanical properties evaluated five times for each of the sample.

**Table 5.2** Summary of the results showing measured values of tensile strength and water contact angle of AASF and surface modified AASF obtained at optimized Ar and Ar + propylene plasma discharge conditions.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Plasma type</th>
<th>RF power (W)</th>
<th>Time (mins)</th>
<th>Flow rate (sccm)</th>
<th>Tensile strength (g/den)</th>
<th>Water contact angle (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASF</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>18.23 ± 1.21</td>
<td>85.9 ± 4.30</td>
</tr>
<tr>
<td>AASF$_{Ar}$</td>
<td>Ar</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>19.02 ± 1.32</td>
<td>90.1 ± 4.54</td>
</tr>
<tr>
<td>PP-AASF</td>
<td>Ar + propylene</td>
<td>40</td>
<td>10</td>
<td>45</td>
<td>32.12 ± 2.25</td>
<td>123.9 ± 6.20</td>
</tr>
</tbody>
</table>
Subsequently the contact angle increased after the grafting of PP on AASF surface as presented in Table 5.2, it is apparent that this is due to the increase in carbon content and carbon containing functional groups (C-C/H/C=O and C-O/C-O-C) after the grafting between AASF and Plasma polymerized propylene.

5.6 Antibacterial Activity

The antibacterial activity of AASF, AASF$_{Ar}$ and PP-AASF is evidenced by an inhibition zone of bacteria (E. coli) growth around them as shown in Figure 5.5 (a) as a typical result. For better comparison, typical FESEM images of AASF, AASF$_{Ar}$ and PP-AASF that are subjected to the present antibacterial examination are also shown in Figures 5.5 (b)-(d). As revealed from FESEM images (Figures 5.5 (c) and (d)), no bacterial growth is observed on the top of and adjacent to AASF$_{Ar}$ and PP-AASF. The results demonstrate that AASF$_{Ar}$ and PP-AASF can inhibit the bacterial growth. However, bacterial growth is observed around and on the top of AASF as revealed from Figure 5.5 (b).

![Figure 5.5](image.png)

**Figure 5.5:** (a) Zone of inhibition test results of AASF, AASF$_{Ar}$ and PP-AASF.
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**Figure b**

[Image of SEM micrograph showing L. coli]

**Figure c**

[Image of SEM micrograph showing layers]

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Table 5.3 presents the experimental results for qualitative evaluation of antibacterial behavior of AASF, AASF_{Ar} and PP-AASF. No clear zone of inhibition can be observed for AASF which clearly indicates its poor antibacterial activity against E. coli. This is likely to be caused by the presence of residual sericin on the surface of AASF that contains significantly high concentration of amino acids having polar side-chain groups [55]. This makes sericin hydrophilic and easily soluble in hot water. On the other hand, the length of the inhibition zone is found to be 16 ± 0.02 mm for AASF_{Ar} and it further increases to 35 ± 0.01 mm for PP-AASF. The increased bacterial resistivity of AASF_{Ar} and PP-AASF against E. coli may be attributed to the removal of residual sericin from the SF surface, change in the state of SF from hydrophilic to hydrophobic environment and enhancement in their semi-crystalline structure. From these results, it can be inferred that Ar plasma treatment acts as an effective technique to sterilize AASF by almost completely removing residual sericin and also possibly other environmental contaminants/impurities present on the surface, that adversely affects the antibacterial activity of AASF against E. coli.
Table 5.3 Antibacterial test results of AASF, AASF$_{Ar}$ and PP-AASF against E. coli. Data presented are the mean ± standard error (S.E.) of zone of inhibition evaluated from three replica sets of experiment.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Zone of inhibition (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASF</td>
<td>0</td>
</tr>
<tr>
<td>AASF$_{Ar}$</td>
<td>16 ± 0.02</td>
</tr>
<tr>
<td>PP-AASF</td>
<td>35 ± 0.01</td>
</tr>
</tbody>
</table>

5.7 Clinical and histopathological examination

Typical photographic images showing closure of surgical wounds of all the three groups of animals using AASF, AASF$_{Ar}$ and PP-AASF and their healing processes in various post surgical periods are presented in Figures 5.6 (a)-(d), Figure 5.7 (e)-(h) and Figure 5.8 (i)-(l). Clinical examination shows minor differences among the three groups of animal starting the 3$^{rd}$ postoperative day. On the 7$^{th}$ postoperative day, the differences are significantly increased for group C animal (Figure 5.8 (j)) whereas the incised wound closure of group A and group B animals show almost similar physical appearance as observed from Figures 5.6 (b) and 5.7 (f). The primary wound healing of group A animals is delayed due to the presence of acute inflammatory signs around the incision site and the sutures are not ready to be removed. Minor bleeding and clot formation is observed in the empty space of the wound and surface sealing as observed from Figure 5.6 (b).

**Group A**

Figure 5.6: Surgical wound closure of group A animals and examination of wound healing at various observation periods. (a) Skin closure of the wound of group A animal with AASF suture. Observation of post operative period of wound healing of group A animals at (b) 7$^{th}$, (c) 14$^{th}$ and (d) 21$^{st}$ post operative day.
On the 14\textsuperscript{th} postoperative day, the inflammatory response is still dominant around the incised wound (Figure 5.6 (c)). No growth of hair is also observed on the skin around the incised wound (Figure 5.6 (c)). On the 21\textsuperscript{st} post operative day, the incised wound develops rash and bump that spreads out the surrounding skin thus indicating incomplete healing (Figure 5.6 (d)). The affected skin becomes swollen and tender, shows no sign of hair growth and is at a higher temperature than rest of the body.

In group B animals, the incised wound show nearly similar development as that of group A animals on the 7\textsuperscript{th} postoperative day. The wound becomes slightly swollen and the acute inflammatory process introduces red patches in and around the incision site (Figure 5.7 (f)). Moreover, no sign of hair growth can be observed on the surrounding skin (Figure 5.7 (f)). On the 14th postoperative day, the group B animals show faster healing process which is characterized by rapid disappearance of acute inflammatory signs, partial epithalization and growth of hair in the surrounding skin (Figure 5.7 (g)). Almost complete healing is observed on the 21\textsuperscript{st} postoperative day where the inflammation in the incised wound has been low, and the surrounding skin is covered with full hair growth without showing any syndrome of red patches, swelling, irritation etc. (Figure 5.7 (h)). The sutures are removed on the 22\textsuperscript{nd} day and the complete healing is observed on the 25\textsuperscript{th} day.

**Group B**

![Figure 5.7: Surgical wound closure of group B animals and examination of wound healing at various observation periods (e) Skin closure of group B animals with AASF\textsubscript{Ar} suture and observation period of the wound healing at (f) 7\textsuperscript{th}, (g) 14\textsuperscript{th} and (h) 21\textsuperscript{st} post operative day.](image)

In group C animals, wound healing is remarkably improved on the 7\textsuperscript{th} postoperative day as evident from the partial regression of inflammatory process around the incised
wound and complete growth of hair in the surrounding skin (Figure 5.8 (j)). On the 9th postoperative day, mild inflammation is observed in the incised wound with no noticeable skin infection around it (Figure 5.8 (k)). The healing period, 11th day after surgery, is characterized by a perfect wound edges approximation with almost disappearance of inflammatory sign and partial recovering of the incised wound with hair growth (Figure 5.8 (l)). The sutures are removed on 12th postoperative day and the healing process is over on 16th day.

**Figure 5.8:** Surgical wound closure of group C animals and examination of wound healing at various observation periods (i) Skin closure of group C animals with PP-AASF suture. Observation of wound healing process of group C animals in the post operative period of (j) 7th, (k) 9th and (l) 11th day post operative day.

The typical histopathology images of tissue samples collected from the incised healing wounds of all the three groups of animal on 14th postoperative day are shown in Figures 5.9 (a)-(c). As revealed from Figure 5.9 (a), the incised wound contains few fibroblasts and less cellular fibrous connective tissues due to poor collagen synthesis that hinders the primary healing process. Collagen plays a central role in healing wounds and it is a principal component of connective tissue and provides a structural framework for the regenerating tissue [54]. Besides, heavy infiltration of the inflammatory cells is observed to be presented in and around the hair follicle as well as the sub-epidermal tissues. The incised wound sutured with AASF<sub>Ar</sub> (Figure 5.9 (b)) shows proliferation of fibrous connective tissues as characterized by large amount of collagen formation and this indicates faster healing of wound as compared to that observed in group A animals.
However as observed from Figure 5.9 (b), mild infiltration can still be seen in and around the hair follicle as well as the sub-epidermal tissues. On the other hand, PP-AASF show remarkable wound healing activity over AASF and AASF$_{Ar}$ that may be attributed to their enhanced antibacterial behavior. From Figure 5.9 (c) it is apparent that the incised wound sutured with PP-AASF contains wavy bundles of dense collagen and considerable proliferation of connective tissues which indicates accelerated healing of wound. Minor infiltration of the inflammatory cells can be observed in and around the hair follicle as well as the sub-epidermal tissues that also contribute rapid healing of the incised wound of group C animals. It is further revealed from Figure 5.9 (c) that comparatively more hair follicle tissues are present in the incised wounds than those sutured with AASF and AASF$_{Ar}$. 
Figure 5.9 Histologic evaluation of wound healing on 14th postoperative day. Histopathological section of the sample collected from the incised wound of (a) group A, (b) group B and (c) group C animals shows inflammatory cell inflammation (IN) in and around the hair follicle (HF) as well as sub-epidermal tissue. Proliferation of fibrous connective tissue (CT) indicates faster healing of group B and group C as compared to group A animals (H & E coloration, 10×).

5.8 Conclusion
In this work, radiofrequency plasma grafted PP-AASF suture is developed and characterized. Prior to grafting, AASF is sterilized in Ar plasma to remove the residual sericin present on its surface. Ar plasma treatment and plasma grafting induce significant conformational (α-helical/random coil→β-sheet) transition in AASF and effectively change the state of SF from hydrophilic to hydrophobic environment. It is apparent that the enhanced semi-crystalline structure, improved hydrophobic property, removal of sericin and tyrosine residues from the SF surface and uniform fibre interlocking in the yarn are the key factors that make PP-AASF to exhibit excellent physical and antibacterial properties than AASF and AASF$_{Ar}$ ones. It is further revealed that the incised wounds of rabbits sutured by PP-AASF contain markedly less inflammatory cell, more hair follicle and connective tissues and dense bundle of collagen fibres that promote healing process faster than that of AASF and AASF$_{Ar}$. Encouraged by the relatively recent progress in this work, PP-AASF can be considered
as a promising biomaterial for application as sterilized suture. However, extensive research is still needed to investigate the \textit{in vivo} biocompatibility and biodegradability of PP-AASF suture to exploit its full potential.
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