EFFECT OF FABRIC STRUCTURE ON DEFECTS IN COMPOSITES MANUFACTURED BY RTM

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Abstract

The effect of fabric structure on defects such as air bubbles, resin-rich areas and cracks in composites manufactured by Resin transfer moulding (RTM) was discussed by analyzing Scanning Electron Microscope (SEM) photographs mainly from two aspects that are fiber layout and seams. Three kinds of reinforced fabrics were used in these composites, including stitched Non-crimp fabric (NCF) of carbon fiber, NCF of glass fiber and 3D fabric of glass fiber. The uneven resin flow, called "fingering" phenomenon by some researchers, was verified by observing a series of sequent stereomicroscope photographs in one injection process. A new concept of "shelving" structure in 3D fabric was also presented.

1 Introduction

Resin transfer moulding (RTM) process, which involves injecting a precatalyzed thermosetting resin under pressure into a heated mold cavity that contains a porous fiber perform, is also known as a liquid transfer molding process. During mold filling, the resin flows into the mold and experiences exothermic curing reactions, causing its viscosity to increase over time and finally solidification. The main issues in the RTM process are resin flow, curing, and heat transfer in porous media.

In an RTM process, resin flow and fiber wet-out are critical. Resin flow within the RTM mold is determined by various parameters, including injection pressure, vacuum in the mold, resin temperature, viscosity, and perform permeabilities. Preform permeability depends on fiber material type, fiber architecture, fiber volume fraction, through-ply vs. in-plane flow, and several other factors. During mold filling, the resin follows the path of least resistance and experiences difficulty when impregnating tightly packed yarns and reinforcing fibers.

Usually several kinds of resin such as epoxy and unsaturated polyesters are used in RTM process. Epoxy is a very versatile resin system, allowing for a broad range of properties and processing capabilities. For unsaturated polyesters, cross-linking reaction between ester and styrene is started by heating or initiator and the resin is cured so that there is no small molecule to generate as same as epoxy. Generally phenolics is not adopted for RTM process due to the fact that water is generated during curing reaction. However, phenolics is sometimes used in RTM for special application.

There are kinds of defects in the composites manufactured by RTM, including air bubbles, resin-rich areas and cracks[1]. The reasons caused these defects are various. Even one defect may be formed by different factors. However, the study on the defect of composites manufactured by RTM is very limited.

In this paper, the effect of fabric structure on the defects in composites manufactured by RTM such as air bubbles, resin-rich areas and cracks was mainly analyzed by Scanning Electron Microscope (SEM) from two aspects that are fiber layout and seams. Stitched Non-crimp fabric (NCF) of carbon fiber, NCF of glass fiber and 3D fabric of glass fiber were adopted as reinforced fabrics, unsaturated polyesters and phenolics were selected as matrix resin.

2 Experimental

2.1 Preparation of composites laminates

The composite laminates were made respectively with three kinds of fabrics such as stitched NCF of carbon fiber (home-made), NCF of glass fiber (Changzhou Hongfa Composite Co. Ltd) and 3D fabric of glass fiber (Tianjin Polytechnic University). The two resin systems are unsaturated polyester resin (Atlac 430LV, Jinling DSM Resins Co. Ltd) and phenolic resin (XD-L872, Xinde Chemical Engineering Machine Co, Ltd).

2.2 Preparation of SEM Sample

First, the samples were chosen from the middle of the laminate with the width of about 10mm. Then a certain cross sections were taken as the observation surface, while several samples were inlayed with epoxy resin at the same time in order to facilitate observation. Then the observation surfaces were sanded with waterproof abrasive papers with model number of 360, 600, 800, 1000, 1200, 1500 and 2000 respectively. At last, the surfaces were polished with antiscuffing paste with a granularity of 2.5 and the samples were put into the ultrasonic cleaner to remove the residual impurities on the surface.

3 Results and discussion

The types of observed defects in composites manufactured by RTM with different kinds of fabrics were almost the same, which are mainly air bubbles, resin-rich areas and cracks. However, microstructure of defects was closely related with the fabric structure, the effect of which was generally caused from two aspects fiber layout and seams.

3.1 Effect from fiber layout

Fiber layout determines the consistence of fiber stack which effects on the local permeability. Non-uniform permeability will cause the uneven flows among fiber bundles (macroflow) and within them (microflow), which differ with the injection pressure as shown in Fig.1. The uneven flow front also called “fingering” phenomenon by other researchers is expressed by actual photographs taken by stereomicroscope as shown in Fig.2. “Fingering” phenomenon is considered as the most important factor to cause defects especially air bubbles.

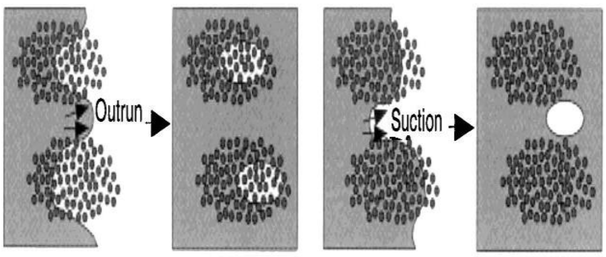
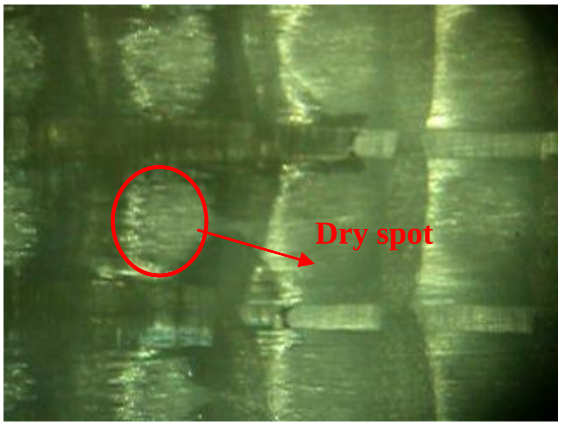
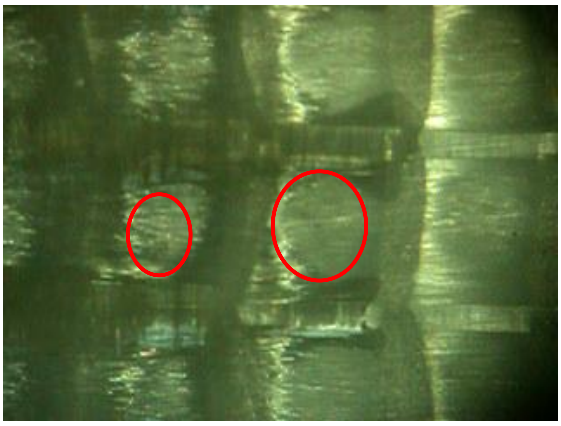


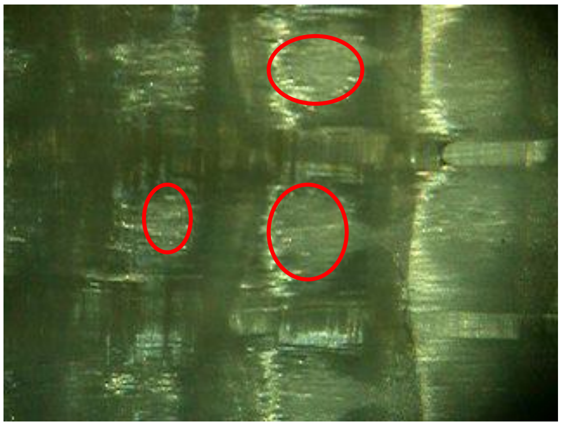
Fig. 1 Scheme of air bubble formation



(a) t =0s



(b) t =2s

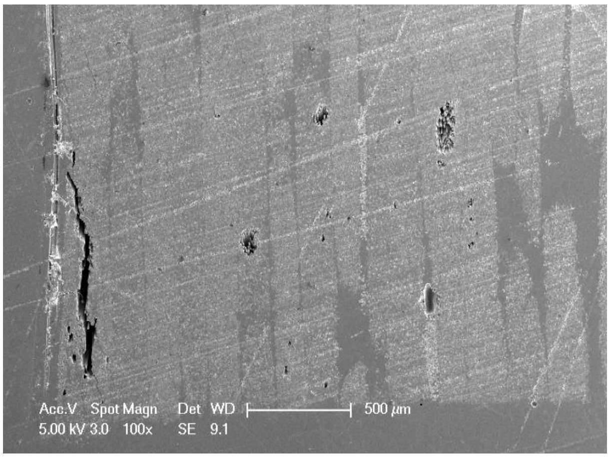


(c) t =5s

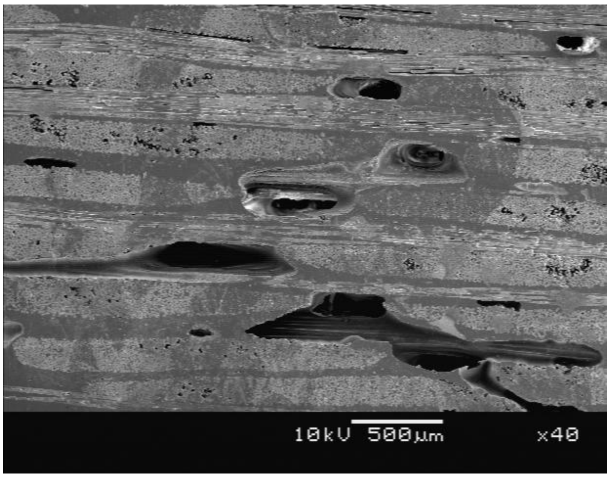
Fig. 2 “Fingering” phenomenon observed by stereomicroscope

3.3.1 Air bubbles

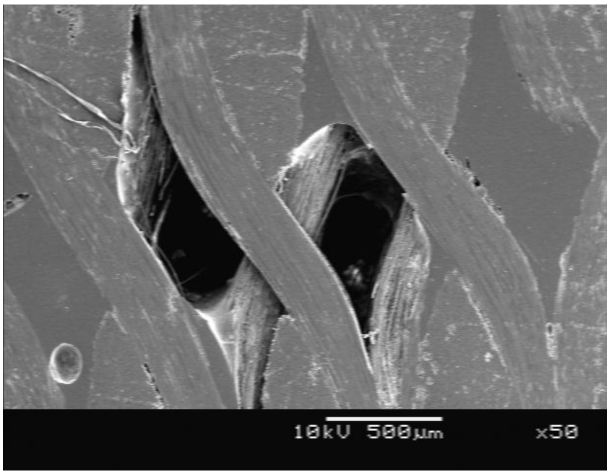
Air bubbles in composites manufactured by RTM with different fabrics have different microstructure. Photographs in Fig.3 are obtained from different reinforced fabrics including stitched NCF of carbon fiber(as shown in Fig.3(a)), NCF of glass fiber (as shown in Fig.3(b)) and 3D fabric of glass fiber (as shown in Fig.3(c)) respectively.



(a) Stitched NCF of carbon fiber (UP)



(b) NCF of glass fiber (Phenolics)

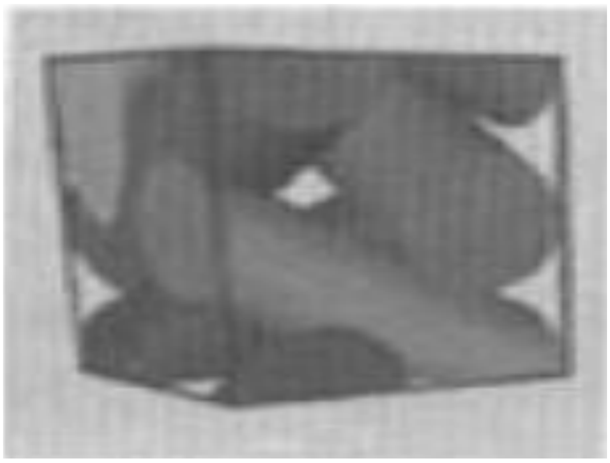


(c) 3D fabric of glass fiber (Phenolics)
Fig. 3 SEM of air bubbles

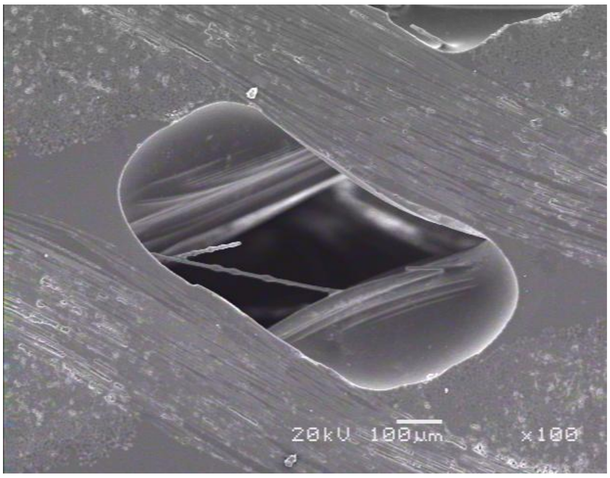
In stitched NCF of carbon fiber (Fig.3 (a)), many layers of carbon fiber warp-knitting fabric are stitched together by Kevlar seam, which reduces the space between layers effectively and correspondingly reduces the difference of permeability between layers and inner layers. Therefore, the observed air bubbles are mainly within the fiber bundles.

In NCF of glass fiber (Fig.3(b)), multiple layers of fabric were stacked together without any seams. Thus, the structure between layers was quite loose with big space, which made the air bubbles appear between layers easily. In addition, because of the special characteristic of phenolic resin, the small air bubbles were apt to aggregate in the area that has relatively low permeability and low pressure.

In terms of 3D fabric of glass fiber, besides uneven resin flow caused by non-uniform permeability, another more important factor that will result in air bubbles is the multi-directional fiber (as shown in Fig.3(c)). In 3D fabric, fibers from different direction were braided and the adjacent fibers are close to each other tightly. A very small space inside multi-directional fibers is formed inevitably. The single cell mold of 3D fabric was simulated by computer as shown in Fig.4 (a), from which the hollow structure inner fibers from different direction was clearly expressed. In the composites manufactured by 3D fabric, such structure that we called “shelving” structure was observed as shown in Fig.4 (b). “Shelving” structure has fibers around it close to each other and air in it, which can be considered as a closed area. During resin infusion, it is difficult for resin flow to replace the air in such area. As a result, in the cured part, “shelving” structure is expressed as big air bubble with a shape almost filling with the whole space within multi-directional fibers, which can be also clearly seen in Fig.3 (c).



(a) Simulation image[6]



(b) SEM photograph (3D fabric of glass fiber/Phenolics)

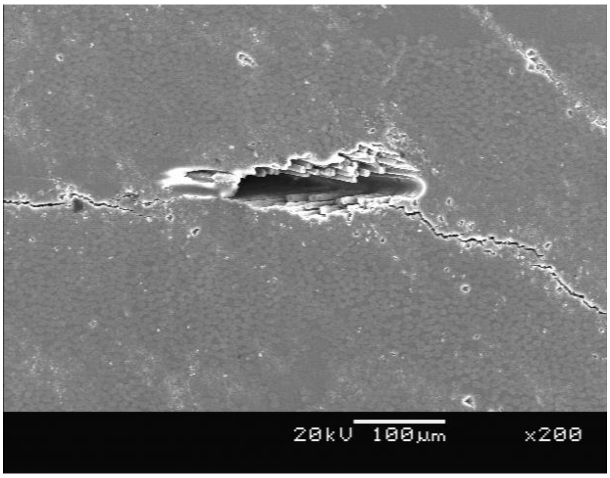
Fig. 4 “Shelving” structure in 3D fabric reinforced composites

3.3.2 Resin-rich areas

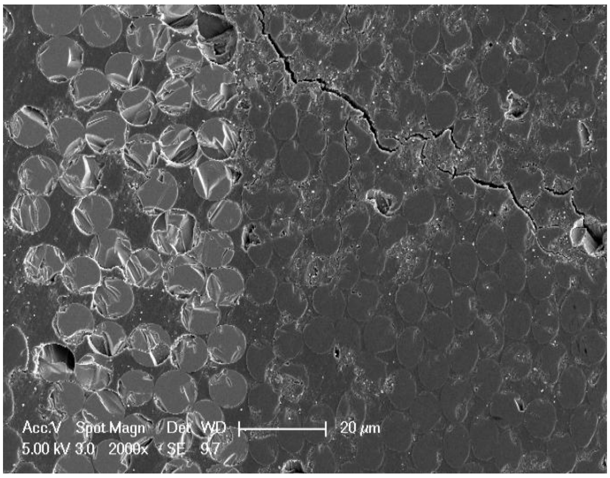
Resin-rich area is another common defect in composites manufactured by RTM. The areas with loose structure have relatively big space without any fibers. If such areas entrap air, it will be presented as air bubble. On the contrary, if such areas are filled with resin, it will be resin-rich areas. Generally, the formation of resin-rich areas is the result of non-uniform permeability. For stitched NCF of carbon fiber, fiber layers are tightened by Kevlar seams, which increase the uniformity of permeability. Therefore, in Fig.3 (a), only a few resin-rich areas were observed. For NCF of glass fiber, as shown in Fig.3 (b), many resin-rich areas were seen between different fabric layers due to the loose structure. It is the same for 3D fabric. Once air in “shelving” structure was replaced by resin, such area will be resin-rich which is shown as the first one from the right in Fig.3 (c).

3.3.3 Resin-rich areas

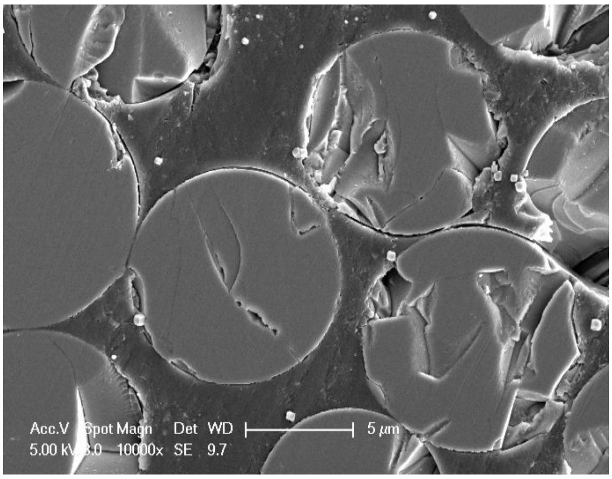
Cracks shown in Fig.5 have different formations. Cracks may origin from the area where the component is different from resin or fiber, such as air bubble with stress concentration (Fig.5 (a)) or seam made of other polymer (Fig.5 (b)). In such condition, the concentrated stress or stress formed due to contraction will be discharged in the form of cracks along the interface between fiber and resin. In addition, when the single fiber filaments stack too close to each other, cracks will also exist along the connect surface for lack of resin as shown in Fig.5 (c).



(a)



(b)

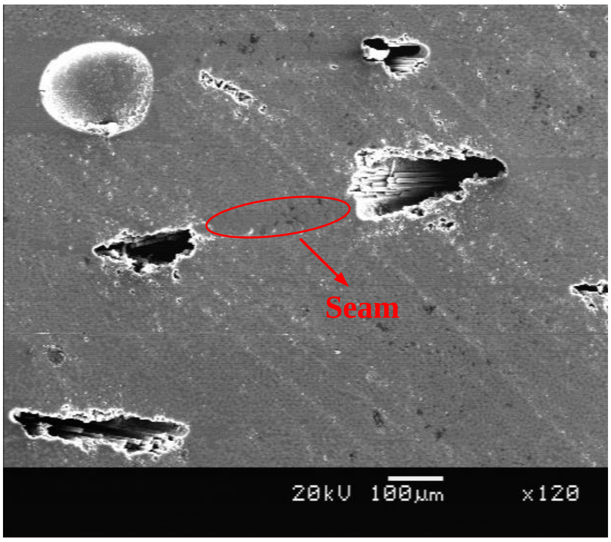


(c)

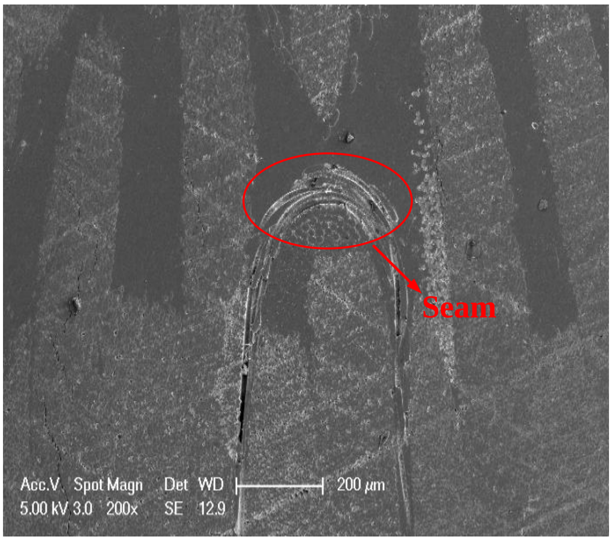
Fig. 5 SEM of cracks (NCF/UP)

3.2 Effect from seams

Seams in the composites referred in this paper mainly have two kinds. One is the Kevlar used to stitch different layers of stitched NCF of carbon fiber. The other is polyester warp-knitting seam. As the third element differing from fiber and resin, the existence of seams will cause defects easily, such as air bubbles (Fig.6 (a)), resin-rich areas (Fig.6 (b)) and cracks (Fig.5 (b)).



(a) Air bubbles besides seams



(b) Resin-rich areas besides seams

Fig. 6 Effect of seams on defects (NCF/UP)

Both Kevlar and warp-knitting seams made the fiber bundles tighter and caused larger loose areas out them. As statement above, if air in the areas outside seams isn't replaced by resin, it will form air bubbles. Else if such areas are filled with resin, then resin-rich areas will be formed. Due to different contraction between seams and resin and fibers, cracks formed along the interface. Therefore, seams made of different materials from fiber or resin will be considered as defect resources to cause air bubbles, resin-rich areas and cracks.

4 Conclusions

By analyzing SEM photographs of composites manufactured with different fabrics by RTM, the effect of fabric structure on defects was discussed. The conclusions are shown as following.

(1) Fiber layout in fabric affects local permeability and then the uneven resin flow during infusion that is also called "fingering" phenomenon resulting in defects such as air bubbles, resin-rich areas and cracks.

(2) For NCF of glass fiber, defects often appear between layers. For stitched NCF of carbon fiber, the number of air bubbles and resin-rich areas is relatively small due to the relatively uniform permeability compared with that in NCF of glass fiber. For 3D glass fiber fabric, it is likely that defects appear in "shelving" structure.

(3) Seams made of materials different from fiber and resin are considered as defect resources in composites. Around seams, it is more likely for defects to appear.

5 References

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