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Research Article

Effects of vacuum infusion configuration on homogeneity of glass fiber reinforced polymer composites for automotive components

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Abstract: In this study, the effects of vacuum infusion configuration on the homogeneities of glass fiber reinforced vinyl ester composites have been evaluated. Three different sizes of samples (100x100 mm, 500x500 mm, and 1000x1000 mm) were fabricated. Three different configurations were used to fabricate the samples. The first two configurations had one inlet, while the third configuration had two inlets for resin infusion. Thickness variations and hardness (Shore D) measurements were performed to determine the homogeneities of the samples. The results revealed that, for small size samples, the configurations have no obvious effect on the homogeneity of the samples, both in terms of thickness variations and hardness values. However, for larger samples, the configuration where the resin is introduced into the preform in the center of the component showed better homogeneity than other configurations. Even a better distribution is assessed with the introduction of the resin in the center of the sample, although this configuration also resulted in thickness swellings in the central areas of the sample. The thickness swellings were observed around the inlet areas for all configurations. The study shows that the resin flow in the center of the component is preferable but thickness swelling must be considered when dimensional tolerances are critical.

Keywords: Vacuum Infusion Configuration, Homogeneity, Glass Fiber Composite, Automotive

1. Introduction

Lightweighting is currently one of the main issues in the automotive industry due to environmental concerns [1]. Producing lighter, more cost effective and eco-friendly vehicles without compromising vehicle safety and product quality is a difficult task. At this point, composite materials are coming to the forefront in the automotive industry. Glass fiber reinforced plastics (GFRPs) composites have been one of the most preferred materials for automotive component manufacturing. GFRP composites have superior advantages such as very high specific strength (strength to density ratio), specific modulus (modulus to density ratio), and high corrosion resistance [2].

GFRP composites are produced with various techniques such as hand lay-up, spray-up, resin transfer molding (RTM), BMC (bulk molding compound) and SMC processes (sheet molding compound) filament winding, and resin infusion processes [3,4]. Vacuum assisted resin infusion molding (VARIM) (shortly named as vacuum infusion, also called VARTM, VM, SCRIMP etc.) process has the optimum properties among the techniques for low volume production of large scale products [5]. Processes such as RTM, BMC, SMC, and filament winding are the processes for mass production and those processes require high tool investments. VARIM processes, on the other hand, is suitable for low volume of production and its most critical advantage is the minimizing the air cavities that have negative effects on mechanical properties of the material in the composite structure. VARIM techniques are applied by stacking the layers on the mold until the desired thickness is reached and after that vacuum is applied to remove air inside the mold cavity. The matrix material (liquid resin) is introduced to the preform via vacuum force and the excess resin is removed from the layers [6]. With this technique, it is possible to fabricate composite materials with minimum resin usage and no air cavities in the material structure that deteriorates the mechanical properties. van Oosterom et al. (2019) compared six different vacuum infusion processes (VARTM, SCRIMP, CAPRI, DBVI, VAP, and PI) and they reported that there is no significant difference in void content of the samples in comparison with each other [7]. Abdurohman et al. (2018) compared the tensile properties of glass fiber reinforced composites with respect to their fabrication methods. The authors fabricated sam-

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ples with hand lay-up, vacuum bagging and vacuum infusion methods. They reported that samples produced with vacuum infusion method had the highest tensile strength and modulus elasticity among the samples [8]. Another important feature of the VARIM techniques that make it attractive is allowance to produce large-scale products [9]. Besides its advantages, VARIM processes also have some disadvantages. Thickness variation is one the major problems with the technique. Many researchers published studies focusing on better understanding and development of VARIM processes. Yenilmez et al. (2011) studied on minimizing the thickness variation by adjusting the injection conditions. The authors reported that the maximum thickness variation was significantly decreased by controlling pening/closing injection/ventilation gates and changing the pressure of the gates [10]. Ricciardi et al. (2013) proposed a different vacuum infusion method called pulsed infusion and they reported that the pulsed infusion improves flexural properties of the composite samples in comparison with conventional vacuum infusion [9].

In this study, the effects of vacuum infusion configuration and surface area on homogeneity of glass fiber reinforced vinyl ester composites have been investigated experimentally. Three different configurations were applied to three different sizes of samples. The thickness variations and hardness values were measured to evaluate the optimum configuration.

2. Material and Method

2.1. Materials

The experimental studies were conducted at laboratories of Automotive Engineering Department, Çukurova University. The glass fibers (biaxial, 300 gr/m^2, 0/90) and vinyl ester resin were purchased and used as received. The properties of the matrix material used for the study are given in Table 1.

2.2. Fabrication of the Samples

Glass fiber/vinyl ester composites were fabricated with vacuum assisted resin infusion process. For production, 3 different configurations were used for different scale samples. For the first configuration (a), the resin was supplied from one side of the preforms and vacuum vent was mounted on the cross side of the preform. For the second configuration (b), the vacuum vent was mounted in the middle of the preform. The resin was introduced from two points in the third configuration (c) and the vacuum vent was mounted on the other side of the preform. The experimental configurations are illustrated in Figure 1 schematically. Also, the photographs given in Figures 2-4 show the application of the configurations. For the experimental studies, total 9 samples (Table 2) were fabricated with configurations above and 3 different sample size. The sizes were selected as 100x100 mm , 500x500 mm and 1000x1000 mm. Each of the samples were fabricated with 5 layers of biaxial glass fibers and vinyl ester resin.

2.3. Testing of The Samples

After the complete curing of the samples (kept as vacuumed and sealed for 24 hours), they were removed from the glass table and each sample was cut into smaller pieces. The thickness values of the samples were measured (at least 5 measurements were recorded for each piece with micrometres and average values calculated) and hardness tests were conducted. The hardness values of the samples were measured with HT-6510D Shore D hardness tester (for each piece at least 5 measurements were conducted). The measurements were not taken from points which are closer to the edges less than 10 mm.

3. Results and Discussions

The experimental samples were fabricated with vacuum infusion technique. The infusion progresses of the configurations are shown in Figures 5-7. The thickness of the samples was measured to determine the dimensional homogeneity through the fabrication process. In infusion-like processes it is quite difficult to produce components with high dimensional tolerances. In Figures 8-10, the thickness measurement results are shown in colormaps.

The thickness measurements showed that, the material thickness varies especially at regions of resin inlet and outlet. The thickness variations were observed for all samples as it is seen in Figures 8-10. For the low surface area samples (100x100 mm), the configuration (c) which had two resin inlet showed slightly better dimensional homogeneity even it had highest thickness variation among the samples. The maximum thickness variation (MTV) values were 0.18, 0.14, and 0.2 mm for configurations a, b, and c, respectively. With the increment of surface area, the MTV values increased which leads to lower dimensional homogeneity. The MTV values of 500x500 mm samples were measured as 0.2, 0.14, and 0.25 mm for configurations (a), (b), and (c), respectively. Those values were 0.3, 0.14 and 0.3 mm for 1000x1000 mm samples. In Figures 11-13, hardness values (Shore D) of the samples are illustrated as colormaps. The hardness measurements revealed that regions thicker regions had lower hardness values due to accumulation of the resin. The thicker regions can also be seen as resin rich which leads

Table 1. Properties of the matrix material

Material	Brand	Chemical	Ratio
Resin	Polives 702	Vinyl ester	-
Curing Agent	AKPEROX A60	Methyl Ethyl Ketone Peroxide	2% of resin (by weight)
Accelerator	AKCOBALT KXC6	Cobalt(II) 2-Ethyl Hexanoate	0.2% of resin (by weight)

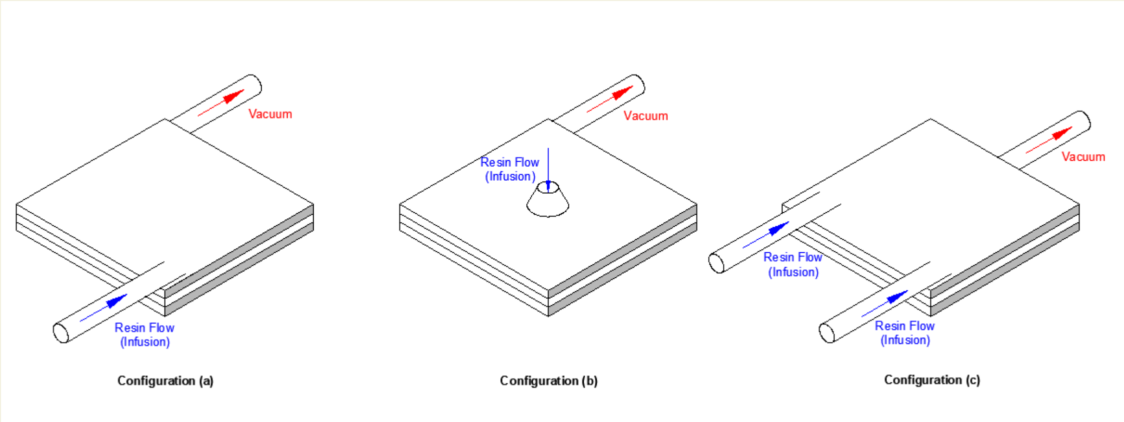

Figure 1. Schematics of the experimental configurations

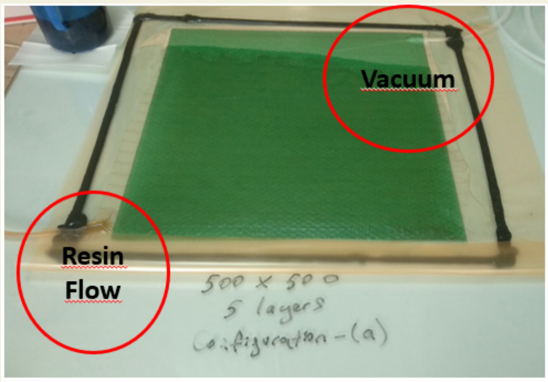

Figure 2. Photograph of the first experimental configuration (a)

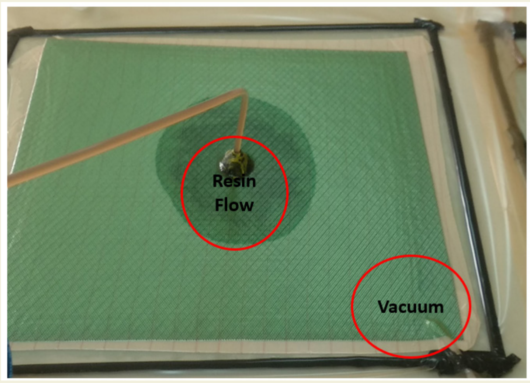

Figure 3. Photograph of the second experimental configuration (b)

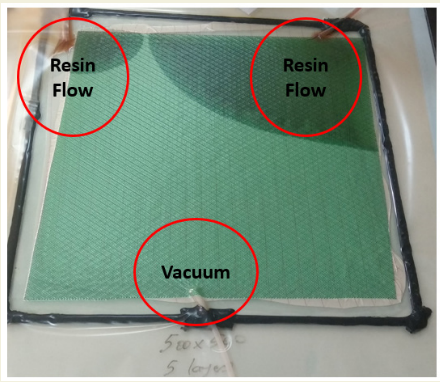

Figure 4. Photograph of the third experimental configuration (c)

Table 2. Experimental design

Specimen No	Specimen Size (length x width) (*mm*)	Surface Area (m^2)	Configuration
1	100x100	0.01	
2	500x500	0.25	a
3	1000x1000	1	
4	100x100	0.01	
5	500x500	0.25	b
6	1000x1000	1	
7	100x100	0.01	
8	500x500	0.25	c
9	1000x1000	1	

to lower fiber fraction ratios. For 100x100 mm samples, the hardness values increased with distance from the resin inlet areas for all configurations. The homogeneities of the samples were deteriorated with increment of the surface area for all configurations. But, configuration (b) showed a better distribution of hardness values than configurations (a) and (c) when surface area increased. For the small surface area, there is no evident difference among the configurations. The thickness and hardness measurements revealed that, configuration (b) which the resin inlet is placed in the middle of the samples shows better homogeneity than other configurations when the surface area is large. But, in contrary, that configuration causes to thickness swelling and low hardness in the middle area of the sample which may create critical problems for the composite products.

4. Conclusions

In this study, the effects of vacuum infusion configuration on different scales glass fiber reinforced polymer composites were investigated to determine the optimum configuration for automotive composite components and the followings were concluded;

- VARIM is an effective technique to produce composite components. With VARIM processes, the air

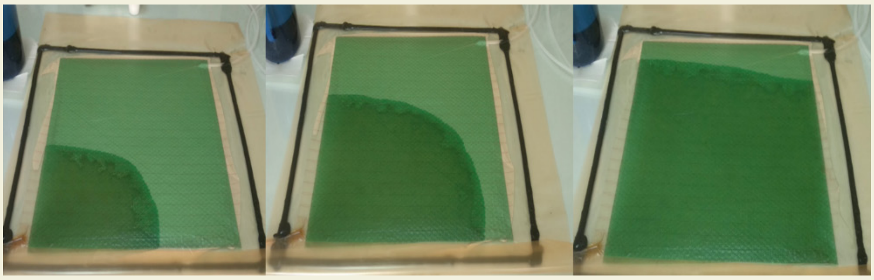

Figure 5. Infusion progress of configuration (a)

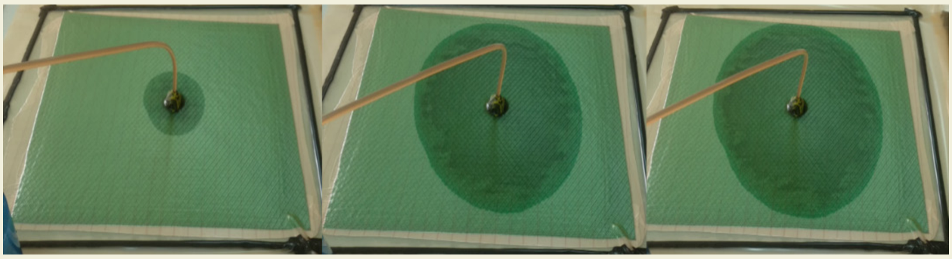

Figure 6. Infusion progress of configuration (b)

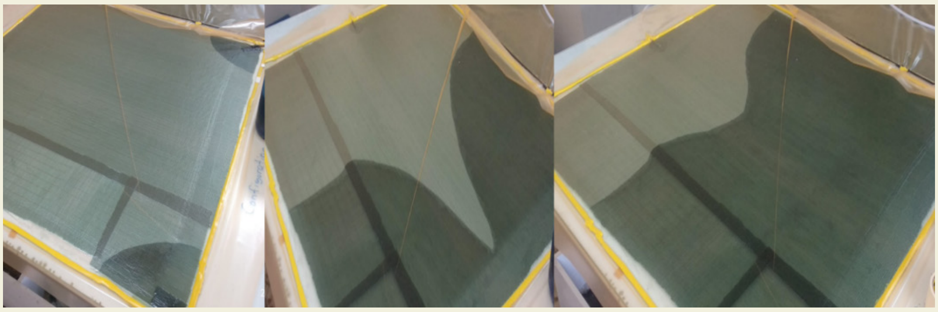

Figure 7. Infusion progress of configuration (c)

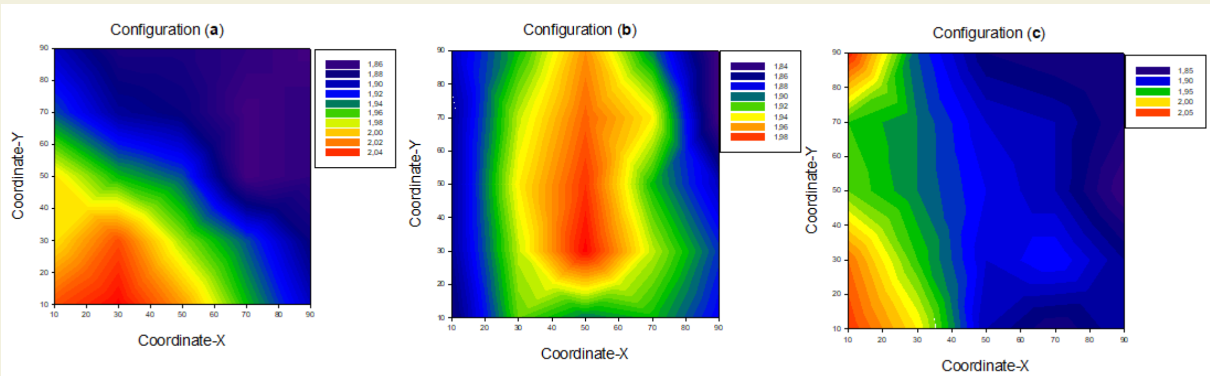

Figure 8. Thickness values of the 100x100 mm samples

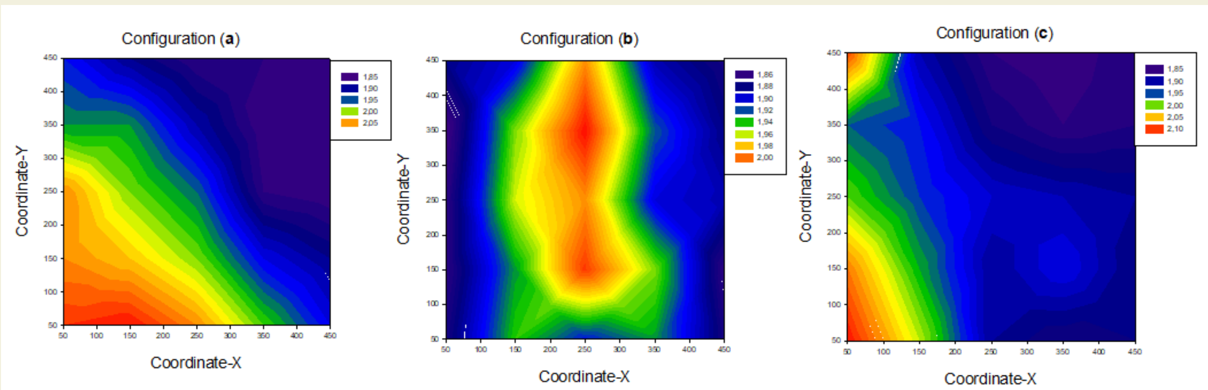

Figure 9. Thickness values of the 500x500 mm samples

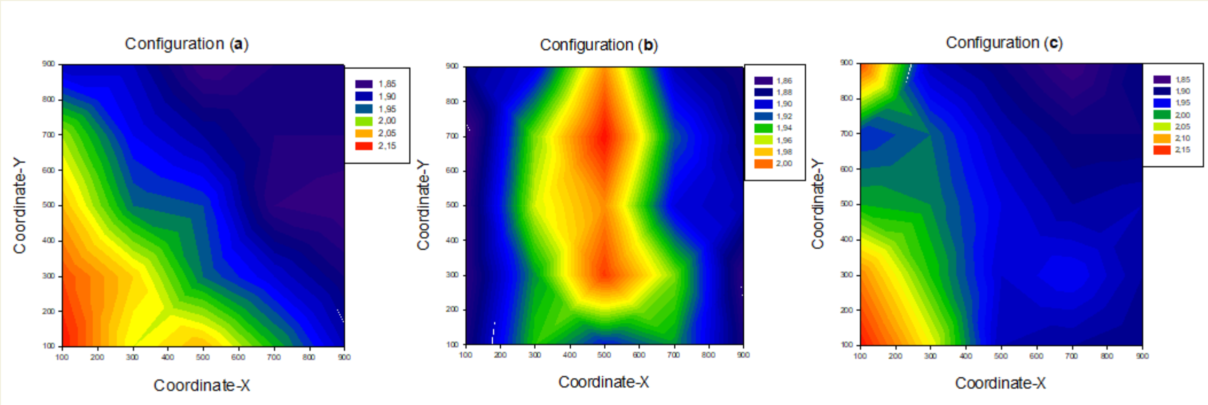

Figure 10. Thickness values of the 1000x1000 mm samples

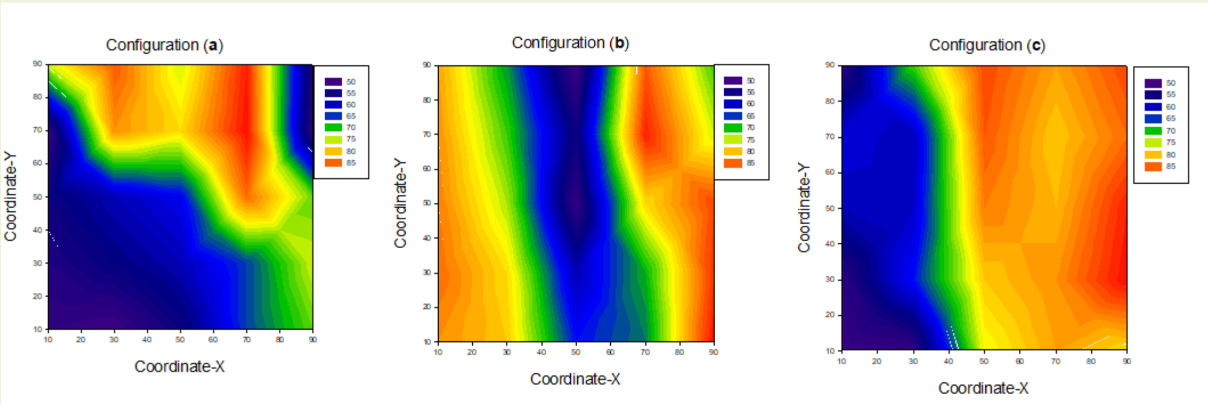

Figure 11. Hardness values of the 100x100 mm samples

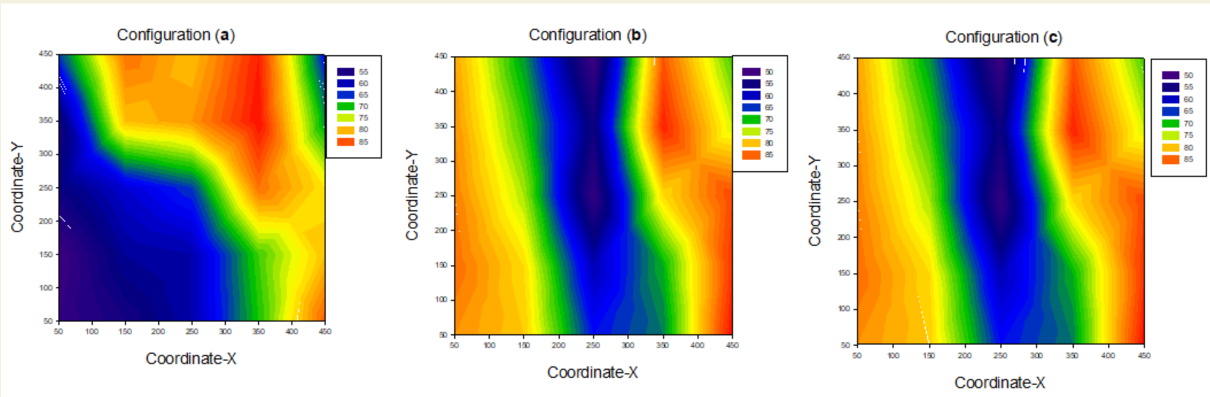

Figure 12. Hardness values of the 500x500 mm samples

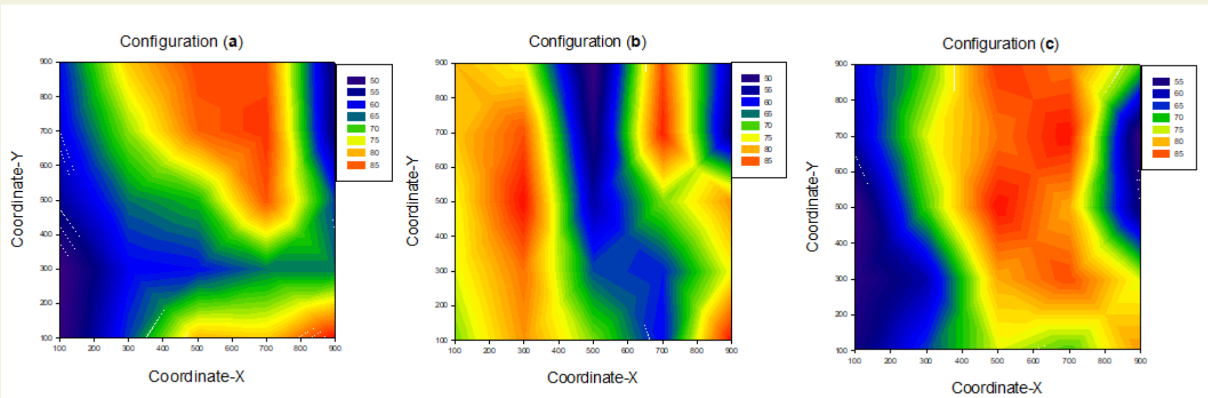

Figure 13. Hardness values of the 1000x1000 mm samples

cavities inside the components are removed and thus better mechanical properties are obtained.

- In VARIM processes, thickness swellings occur in the regions of resin inlet. And thus, it is difficult to produce composite components with high dimensional tolerances.
- The homogeneity of the composite material deteriorates with the increment of surface area.
- For small surface area components, the configurations do not have evident effect on homogeneity.
- For large surface areas, configuration should be carefully selected. The configuration which resin is introduced in the middle of sample provides better distribution of the matrix material but, the thickness swelling in the middle of the component have to be considered.

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