A Comparative Study of Mechanical Properties Using Different Kenaf Yarn Linear Density at Different Stacking Angle of Multi-Layer Woven Preforms Composite

Mohd Pahmi Saiman [1*], Md Saidin Wahab[2], Harintharavimal Balakrishnan[3] and Mat Uzir Wahit[3]

[1]*Jabatan Kejuruteraan Mekanikal, Politeknik Seberang Perai, Jalan Permatang Pauh, 13500 Permatang Pauh, Pulau Pinang.*
[2]*Advanced Manufacturing & Mechanical Centre (AMMC), Universiti Tun Hussein Onn Malaysia, Malaysia.*
[3]*Centre for Composites (CfC), Universiti Teknologi Malaysia, Malaysia.*

ABSTRACT

The study investigated the effect of main parameter of fabric geometry for 2D woven kenaf as reinforcing agent in natural based multi-layer polyester composite. The manipulation on the primary parameters consisting of different linear density and fabric construction with constant weave design capable to change the secondary parameters which affect the mechanical properties of the multi-layer composite. The multi-layer composite were infused with unsaturated polyester using vacuum infusion process in different stacking angle. It was shown that using fine yarn on the dry woven kenaf structure it can increase the mechanical properties due to the influence of matrix pocket size. The stress direction influence mechanical properties whereby stacking angle of 0°0°0° is recommended to increase the tensile strength while stacking 0°45°0° is good for flexural strength due to multiple direction of load.

INTRODUCTION

The use of natural fibres as reinforcing agent to replace synthetic fibres such as glass, carbon and aramid in polyester composites is becoming increasingly popular. Kenaf is one of the natural fibres and has traditionally been used as cordage crop to produce twine, rope, gunny-bag and sackcloth [1]. Kenaf's bast fibre is expanding into new markets of moldable, nonwoven fabrics, and reinforced composite materials in automotive, aerospace, packaging and other industrial applications.

Generally, natural fibres in composite may be constructed oriented randomly, unidirectional or biaxial according to the technique and the properties concerned. Two dimensional (2D) woven composite is one of the textile composite based on the formation of textile reinforcement with polymer matrix [2]. The reinforce material is produced by mechanically bonding two or more fibre bundles (also known as yarns) together in a specific architecture (e.g. plain weave, twill, satin, etc.) by means of interlacing warp and weft yarns [3]. However, the parameters controlling the mechanical properties of textile composite are numerous such as the weave architecture, fibre properties, matrix properties, etc.

Naik [4] and Lee et al. [5] reported that other than textile reinforced parameter, one of the main techniques used to increase the mechanical properties of textile composite is laminate technique. A laminate composite has a number of layers or lamina and the orientation of the fibres are dependent on the application of the load direction. It is believed that the stacking orientation and overall fibre volume fraction influenced the mechanical properties of laminate composite the most. If the laminate is to be subjected only to an axial load causing tension, the

*Corresponding Author: *pahmi.saiman@gmail.com*

fibres in all layers should have the same load orientations in order to obtain the greatest possible strength. However, if the load is in different direction such as in compression, it is more stable by positioning some of the layers of the fibres perpendicular to the load. The position of some layers at 30°, 45°, or 60° to the load may increase the resistance of the laminate [6].

Structural reinforced material is commonly processed based on liquid composite molding (LCM). A vacuum infusion process (VIP) is categorized in LCM consisting of a closed mold with a one rigid mold sealed and a vacuum bag [7]. It has many advantages which are low cost compared to hand layup or autoclave and increased mechanical properties by increased void free fibre volume. Along with increasing health awareness, the usage of closed mold technique and changing environmental regulations has driven VIP to its popularity [8-9]. The implementation of this technique required a good processing strategy combined with the material used and a reliable and quick manufacture [8].

The capability of VIP to infuse the reinforced material also depends on the resin used. Unsaturated polyester (UPE) is a matrix resin usually used as a binder in fibre reinforced polymer (FRP) products. It is one of the most popular thermosetting resins due to its low cost, excellent process ability and good crosslinking tendency with good mechanical properties. It is been used for many years in a broad range of applications such as naval construction, offshore applications, waterlines, building construction [10-11]. The capability of a room or low temperature setting makes it possible to process at low pressures and ease of handling in processes like hand lay-up, filament winding and VIP. Natural fibres combined with UPE resin is widely used in industrial applications compared to other thermosetting resin due to its room temperature cure capability, good mechanical properties and transparency [12].

In this study, 2D woven kenaf reinforced unsaturated polyester composite was prepared. The processing techniques and the mechanical properties of the kenaf reinforced polyester composites were studied in detail. It is well known in synthetic engineering material application but in terms of natural based structural composite, much remains to be studies. Many studies on the structurally natural based woven composites have neglected the basic formation of the reinforced structure that would affect the properties of the composites. This is important as the emphasis on the structural formation of the preform will determine the ability of the composite. Therefore, this study is focusing on the parameters of the 2D woven kenaf structure formation to enhance the mechanical properties of the multilayer composite.

EXPERIMENTAL

Materials

The kenaf yarn was supplied by Juteko Bangladesh Pvt. Ltd, Dhaka, Bangladesh with linear density of 276tex and 759tex. Unsaturated polyester resin (2597P-I) was used as the matrix and methyl ethyl ketone peroxide (MEKP) as the catalyst were provided by Wee Tee Tong Chemical Pvt. Ltd., Singapore.

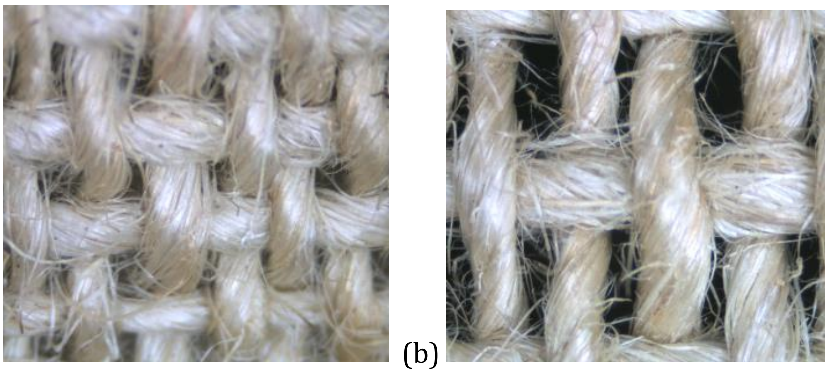
Preparation of 2D Woven Kenaf

The yarns were woven into plain fabric using a floor loom. The findings shown in Table 1 indicate an unbalanced preform. However, according to Sondhelm [13] for constant plain weave fabric the cover factor of warp or weft direction is 14 while above 16 it was considered as a jam structure. In such situation, the warp and weft yarns do not have mobility within the structure as they are in intimate contact with each other [14]. The result shows that the preforms are below 16 and although 276tex has the highest value it is still considered as constant fabric. The warp cover factor has been calculated according to Equation 2. The actual preforms for both yarns are shown in Figure 1 and 2.

Table 1 Actual preform for plain woven kenaf

Linear density	276tex	759tex
Warp × weft per cm	9×7	5×4
Areal density, g/m²	467	739
Warp cover factor	14.95	13.77

$$Cover\ factor\ (S.I.) = \frac{\frac{Treads}{cm}}{10} \times \sqrt{Tex} \tag{1}$$



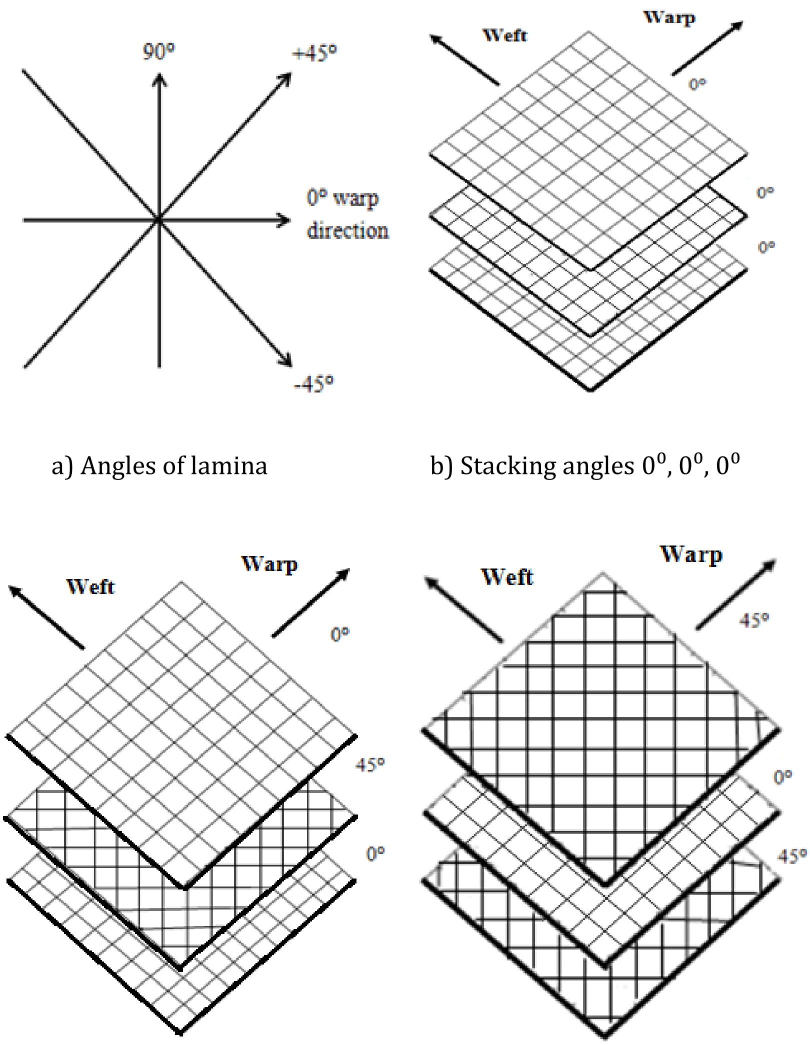
(a) (b)

Figure 1. Plain fabric image under microscope of 7× magnification for (a) 276tex (b) 759tex.

Figure 2. Woven kenaf preform.

Fabrication of Multi-Layer Composite Panels

The woven kenaf for both yarn sizes was fabricated into multi-layer composites panel using VIP. Due to unbalanced fabric or unequal yarns in warp and weft direction, the fabric samples were cut according to warp direction. The fabric samples were stacked following the angle ply as shown in Figure 3. The placement of the preforms is on a flat surface of the mold and covered with flexible VIP parts. The UPE was infused using vacuum pump from the inlet hose and distributed evenly throughout the woven fabrics and out to vacuum outlet inside the resin trap. After infusion, the resin was cured for 24 hours.



a) Angles of lamina   b) Stacking angles 0^0, 0^0, 0^0

c) Stacking angles 0^0, 45^0, 0^0 d) Stacking angles 45^0, 0^0, 45^0

Figure 3. Woven fabric angle ply with three different stacking angles.

Table 2 shows the properties of the composite panels for 276tex and 759tex. The thickness of the composite panels showed a slight difference between each yarn linear density. The percentage of fibre volume ratio (V_f) for each linear density in form of preform and composites are similar. This because VIP used a mold which was rigid at the bottom and flexible at the top. As a result, the ratio of the infused resin was almost the same as the rest of the preform. Therefore, the composites show a good comparison with each other having the same V_f.

Table 2 Actual preform for plain woven kenaf

Linear density	**Stacking angle**	**Plate thickness, mm**	**V_f, %**
	$0^0 0^0 0^0$	3.64	33.65
276tex	$0^0 45^0 0^0$	3.44	31.25

	$45^0 0^0 45^0$	3.45	30.43
	$0^0 0^0 0^0$	5.40	32.35
759tex	$0^0 45^0 0^0$	6.12	30.64
	$45^0 0^0 45^0$	5.98	30.52

Mechanical Analysis

The multi-layer woven kenaf composites panel of 276tex and 759tex were characterized by mechanical testing. The tensile and flexural tests were conducted using LLYOD, LR30K Universal Tensile Machine and the test sample was conducted only on the warp direction. The tensile test for the composite was carried out according to ASTM D3039 where each test used five specimens at a crosshead speed of 1mm/min.

The flexural test used ASTM D 790 Standard Test Methods for "Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials". The rate of crosshead motion is according to the Equation 2.

$$R = \frac{ZL^2}{6d} \tag{2}$$

Where,

R = rate of cross head motion, mm/min
Z = rate of straining of the outer fibre, mm/mm/min = 0.01
L = support span, mm
d = depth of beam, mm

Five specimens per series were used in this test and the specimen specifications are according to composite thickness greater than 1.6mm. Both test methods were conducted according to ASTM D6856/D6856M standard guide for testing "Fabric-Reinforced Textile Composite Materials".

RESULTS AND DISCUSSION

Tensile Properties

Figure 4 shows two different linear density consisting of 276tex yarn and 759tex composite with three different stacking angles of $0^0 0^0 0^0$, $0^0 45^0 0^0$ and $45^0 0^0 45^0$. The result showed that the stacking angle of $0^0 0^0 0^0$ is the strongest as the strength of the yarns is in the direction of the stress been applied during tensile test. It shows that when the warp yarns direction was parallel with the stacking angle and the stress direction, it would work together to undertake the tensile stress resulting in a greater tensile strength. Previous study by Gu [15] also reported similar observation. It is followed by $0^0 45^0 0^0$ when two layers of the woven kenaf are in the direction of the stress applied. Last, the $45^0 0^0 45^0$ stacking angle shows the weakest as only one layer is in the direction of stress being applied when the two layers are in different angle. It can be summarized that 0^0 (warp wise) ply orientations are suitable to carry loads in the longitudinal direction. The 90^0 (weft wise) ply orientations are suitable to react to load in the transverse direction and the 45^0 ply orientations are to respond to shear loads.

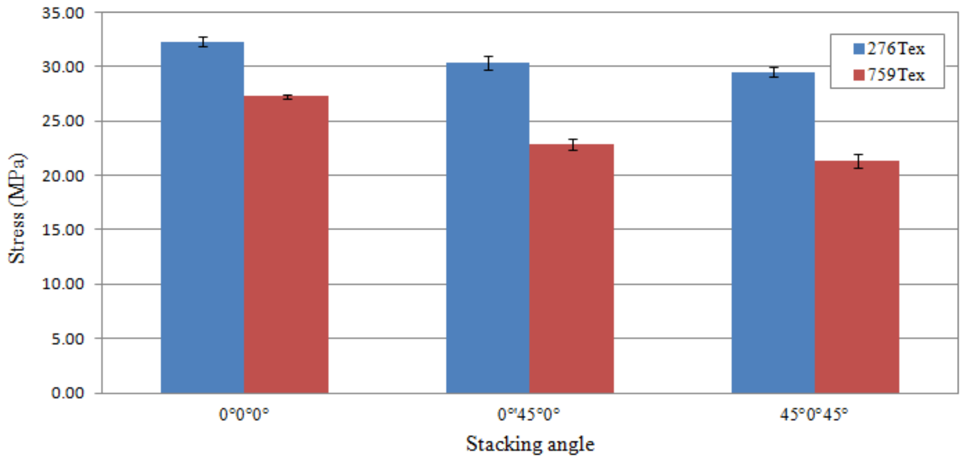


Figure 4. Tensile stress of 276tex and 759tex woven kenaf composite.

Figure 5 shows the tensile modulus also followed the trend of tensile strength with the highest value begins with a stacking angle of $0^0 0^0 0^0$ followed by $0^0 45^0 0^0$ and lastly $45^0 0^0 45^0$. It shows that reduction of tensile modulus occurs when there are different orientations with the applied load. In this situation, the stacking angle of $45^0 0^0 45^0$ is the lowest followed by $0^0 45^0 0^0$ due to different orientation of the fabric lay-up. The $0^0 0^0 0^0$ is the highest as the orientation between fabrics is in a parallel direction resulting in excellent strength. In the situation of cross-ply laminate composite, it is well known for the stiffness reduction when fibres bundles are oriented transverse to the main loading direction as a function of transverse crack [16-17]. In form of biaxial laminate composite, transverse crack may occur but the surface orientation determines the damage level of the composite. In this condition, the 45^0 at the surface and 45^0 at the back of composite has reduced the stiffness properties.

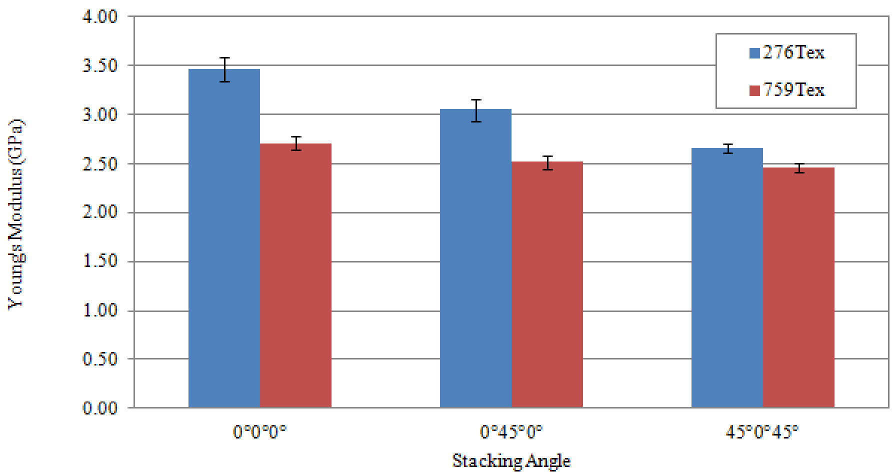


Figure 5. Young's Modulus of 276tex and 759tex woven kenaf composite.

In the case of different yarn fineness, the trend for both graphs (Figure 4 and Figure 5) had shown a same pattern between 276tex and 759tex of yarn. The 276tex indicated high tensile strength and stiffness properties compared to 759tex of yarn. The results showed that the use of 276tex of yarn for multilayer woven kenaf composite is much better compared to 759tex of yarn. According to Gerlach et al. [18-19], the failure in a multilayer composite occured due to the interface between yarns and matrix pocket (gap between interlaced yarns) within textile composite. The size of the matrix pocket determines the efficiency of the binder between layers. Low area of matrix pocket (276tex) may consist of excellent delamination resistance. The delamination is the result of accumulated matrix microcracking and when a load is applied, the matrix pocket begins to microcrack and the composite begin to soften. The results show that the use of 276tex of yarn for multilayer woven kenaf composite is much better compared to 759tex of yarn.

Flexural Strength

Figure 6 showed that the average flexural strength for 276tex is much superior compared to 759tex. The result has followed the result of tensile strength showing fine yarn is more suitable for laminate composite in terms of tensile and flexural strength. There is a correlation between stacking angle and flexural strength of the laminate composite. It shows that the stacking angle of $0^0 45^0 0^0$ is superior in flexural strengh followed by $45^0 0^0 45^0$ and stacking angle of $0^0 0^0 0^0$. The stacking sequence of the reinforced woven kenaf is important when it is in multi-axial load. The stack is symmetrical which helps to eliminate any tendency to bend. As reported in previous study [20], the dominant orientation of outer layer will affect the flexural strength. The 0^0 of the sample consists of warp yarn orientation which is transverse with the flexural load and hence this result exhibited higher flexural properties. In fact, there is an agreement for stacking angle of 0^0 without any diagonal laminas 45^0 which will reduce the flexural strength due to vertical cracking of the composite [21]. Therefore, strengthening the skin parts using stacking sequence of 0^0 at the top followed by strengthening the core parts using 45^0 at the mid plane is a more effective approach when flexural loading is applied to the multilayer structure [22]. Using a same stacking angle of $0^0 0^0 0^0$ in a multi axial load, the durability of the composite is low due to the fibre orientation.

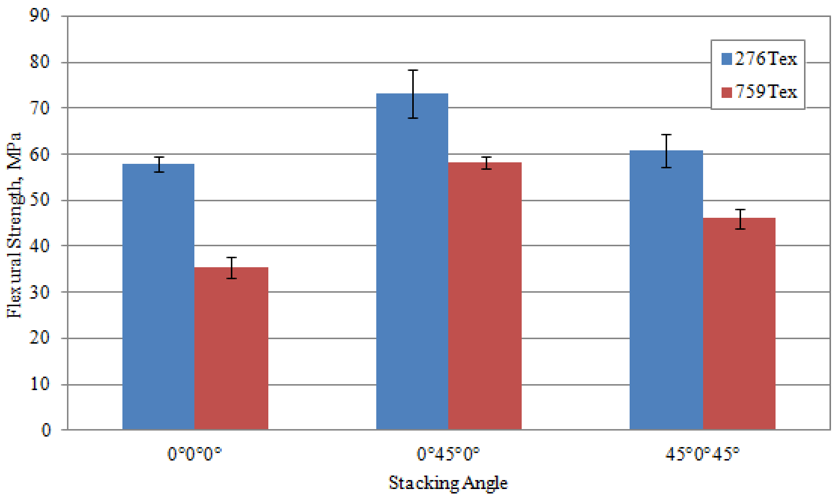


Figure 6. Flexural strength of 276tex and 759tex woven kenaf composite.

CONCLUSION

The development of 2D woven kenaf structure of multi-layer composite has been studied. The fabrication of different oriented stacking angle of multi-layer composite using VIP with two different yarn linear density, optimal fabric count and fixed plain weave indicate a significant difference in mechanical properties. The use of fine yarn with stacking angle $0^0 0^0 0$ indicated a better result compared to coarser yarn in terms of tensile properties. The size of the matrix pocket and the stacking angle according to the direction of the stress are the main factors in increasing the tensile strength. It also occurs with flexural strength but the stacking angle of $0^0 45^0 0^0$ is the most appropriate as the fibre orientation involved in multiple direction of load.

REFERENCES

B.G. Ayre, K. Stevens, K.D. Chapman, C.L. Webber, K.L. Dagnon, N.A D'Souza, Tex. R. J., **79**, 973-980 (2009)

S.L. Ogin, *Textile-reinforced composite materials* (Woodhead P. Ltd., Cambridge, 2004)

M. Komeili, A.S. Milani, Comp. & Struc., **90-91**, 163-171 (2012)

R.A. Naik, J. Comp. Mtls., **29**, 2334-2363 (1995)

S.K. Lee, J.H. Byun, S.H. Hong, Mtls. Sci. & Eng. A, **347**, 346-358 (2003)

F.P. Beer, E.R. Johnston, Jr. & J. T. DeWolf & D. F. Mazurek, *Mechanics of materials* (McGraw-Hill, New York, 2012)

N.C. Correia, F. Robitaille, A.C. Long, C.D. Rudd, P. Šimáček, S.G. Advani, Comp. Part A: Apld. Sc. & Mfg., **36,** 1645-1656 (2005)

W.D. Brouwer, E.C.F.C. Van Herpt, M. Labordus, Comp. Part A: Apld. Sc. & Mfg., **34,** 551-558 (2003)

D. Modi, M. Johnson, A. Long, C. Rudd, Comp. Sc. & Tech., **69,** 1458-1464 (2009)

M.L. Beatriz, R.E. Santos, W.P. Maria, V. Analía, Poly. Degrad. & Stb., **91**, 255-261 (2006)

M.A. De Farias, M.A. Farina, A.P.T. Pezzin, D.A.K. Silva, Mtls. Sc. & Eng.: C, **29,** 510-513 (2009)

Rashdi, A.A.A. Sapuan, S.M. Ahmad, M.M.H. Megat, K. Abdan, J. of Food, Agri. & Env., **7**, 908-911 (2009)

W.S. Sondhelm, *Technical fabric structures - 1. Woven fabrics* (Woodhead P. Ltd., Cambridge, 2004)

B.K. Behera, J. Militky, R. Mishra, D. Kremenakova, *Modeling of Woven Fabrics Geometry and Properties* (InTech, Croatia, 2012)

H. Gu, Mtl. & Des., **27,** 1086-1089 (2006)

M. David, J. Roberts, J. Varna, Eng. Frac. Mech., **75,** 2666-2682 (2008)

R. Joffe, J.A. Varna, Comp. Sci. Tech., **59**, 1641–52 (1999)

R. Gerlac, A. Palast, N. Petrinic, A. Horning, J. Wiegand, C.R. Siviour, W. Hufenbach, Comp. Sci. & Tech., **69,** 2024-2026 (2009)

R. Gerlac, C.R. Siviour, J. Wiegand, N. Petrinic, Comp. Sci. & Tech. **72,** 397-411 (2012).

M. Mariatti, M. Nasir, H. Ismail, Poly. Test., **21**, 807-814 (2002)

H. Sakurabaa, T. Matsumoto, T. Hayashikawa, Pocedia Eng., **14,** 1845-1854 (2011)

I.L. Lim, K.Y. Rhee, H.J. Kim, D.H. Jung, Carbon Letters, **15,** 125-128 (2014)