Analysis of Mechanical Properties of Carbon-Based Hybrid Composites as an Alternative for Amphibious Aircraft Float Material

Kosim Abdurohman[1], Mohammad Adhitya[2]

[1]National Institute of Aeronautics and Space – LAPAN, Rumpin, Bogor 16350, Indonesia
[2]RCAVe (Resesarch Center for Advanced Vehicle Universitas Indonesia), Kampus UI Depok 16424, Indonesia

[1]e-mail: kosim.abdurohman@lapan.go.id

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Abstract

The high specific stiffness and strength of composites make them widely used in defense, marine, and aerospace applications. Hybrid composites have increased use in high-tech applications, one of them is as an amphibious aircraft float material. The glass/carbon and KC/carbon hybrid composites manufactured by VARI methods are used in this study. The fibers used are woven roving carbon fabric and woven cloth e-glass fabric for glass/carbon hybrid composites; and woven roving carbon fabric and hybrid woven roving kevlar-carbon fabric for kevlar-carbon/carbon hybrid composites. The matrix used for both composites is vinyl ester resin. The mechanical properties are evaluated according to ASTM standards. Fracture micrograph analyses are investigated using SEM. The comparison of mechanical properties and surface fracture of both hybrid composites have been investigated by the author. The tensile and compressive strength of KC/carbon is higher than glass/carbon hybrid composites up to 11% and 9%, respectively. SEM micrograph exhibits that the KC/carbon has a good fiber/matrix and interlayer bond better than glass/carbon hybrid composites. The study results exhibited that the hybrid composite with the most potential as an alternative to amphibious aircraft float material is the KC/carbon composite.

Keywords: *hybrid composites; hybrid fiber; resin infusion; kevlar-carbon; mechanical properties.*

Nomenclature

C	=	Carbon fiber
C_3	=	Three-ply carbon fiber
G	=	Glass fiber
G_2	=	Two-ply glass fiber
K	=	Kevlar fiber
KC	=	Kevlar-carbon hybrid fiber
$(KC)_2$	=	Two-ply kevlar-carbon hybrid fiber
s	=	symmetric

1. Introduction

Aircraft that can take off and land in water environment are called amphibious aircraft. It has a float and landing gear to maintain stability when landing in water (Dawei, Zheng, Landing, & Jizhong, 2011). Some manufacturers use aluminum as the amphibious float material while other manufacturers use fiber reinforced composite materials. Aluminum which is usually used as a float material is Al 6061-T6 with a tensile strength of 310 MPa, a compressive strength of 234 MPa, and a shear strength of 207 MPa (ASM, 2012).

Fiber-reinforced polymer composites are the most attractive type of composites due to their extensive use in structural, mechanical, and automotive components (Chinnasamy, Subramani, Palaniappan, Mylsamy, & Aruchamy, 2020). Their high specific stiffness and strength made them widely used in defense, marine, and aerospace applications (Naveen, Jawaid, Zainudin, Sultan, & Yahaya, 2019). Carbon and glass composites are attractive for producing the next generation of materials due to their high strength-to-weight ratio. The positive effect of hybridization is obtained when glass layers are placed on the outer layer of the hybrid composites as stated by Bulut *et al.* in (Bulut, Erkliğ, & Yeter, 2016). Several types of fibers used in hybrid composites include glass, carbon, and aramid fibers. Numerous of study utilized glass/carbon (Ahamed, Joosten, Callus, John, & Wang, 2016; Ahamed, Joosten, Callus, Wisnom, & Wang, 2016; Chen, Sun, Meng, Jin, & Li, 2019; Dong, 2016; Dong & Davies, 2012, 2014a, 2014b; Dong, Kalantari, & Davies, 2015; Dong, Ranaweera-Jayawardena, & Davies, 2012; González, Maimí, Sainz de Aja, Cruz, & Camanho, 2014; Kalantari, Dong, & Davies, 2016a, 2016b; Kedar S. Pandya, Jayaram R. Pothnis, G. Ravikumar, 2013; Song, 2015; Zhang, Chaisombat, He, & Wang, 2012), aramid/carbon (Song, 2015; Zheng et al., 2017) and aramid/glass (Bandaru, Vetiyatil, & Ahmad, 2015; Chinnasamy et al., 2020) as the major hybrid composites. Another study utilized aramid and natural fiber reinforced hybrid composites (Amir et al., 2019; Da Silva et al., 2020; A. Kumar, Patel, Sachan, Ahmad, & Alagirusamy, 2016; Naveen et al., 2019; Silva, Monsores, De Oliveira, Weber, & Monteiro, 2018; Singh et al., 2019).

Studies of glass/carbon hybrid composites are conducted in several kinds of laminas hybridization. The study of S-2 glass and T700 S carbon by Dong and Davies in (Dong & Davies, 2014a) exhibited that elastic modulus of tensile reduced by the increase of glass in hybrid ratio. Otherwise, the maximum tensile strength is attained when the hybrid ratio of glass is the lowest and the volume fraction of carbon and glass fiber are 30% and 50%, respectively as the result of Dong and Davies study in (Dong & Davies, 2014b). The tensile strength of [C_2G_2]s and [CGCG]s composites are similar; nevertheless, the compressive strength of [CGCG]s is higher than [C_2G_2]s. These indicate that the stacking sequence of the same hybrid composition influences the compressive properties significantly than the tensile properties as stated by Zhang *et al.* in (Zhang et al., 2012). Other studies by Song in (Song, 2015) show that lying carbon fiber in the center of laminate [GCG] makes the composite strength and stiffness superior to placing it on the exterior [CGC] of glass/carbon laminate.
Several types of research utilized aramid fiber hybridization with glass, carbon, and natural fiber to know the characteristics of these hybrid composites. The strength and stiffness of aramid/carbon hybrid composites are superior when the carbon fibers are placed in the center of laminate [ACA] than those on the outer of laminate [CAC] as stated by Song in (Song, 2015). A study on carbon/aramid hybrid 3D braided composites by Zheng *et al.* in (Zheng et al., 2017) exhibited that tensile strength and modulus are higher for composites with axial yarns of carbon fibers than those of aramid fibers. Other studies on absorbed energy by Bulut et al. in (Bulut et al., 2016) exhibited that CKC (carbon-kevlar-carbon) hybrid composites showed the highest positive effect of hybrid, while the CGC exhibited the highest negative effect of hybrid. However, hybridization of kevlar and carbon fiber exhibited superior ballistic impact resistance than those of Kevlar and glass fibers as the result of Bandaru *et al.* study (Bandaru et al., 2015). Hybridize composites with 25 wt.% of cocos Nucifera sheath and 75 wt.% of kevlar fiber reduced the tensile properties by 19% as stated by Naveen *et al.* in (Naveen et al., 2019). A study by Kumar *et al.* in (A. Kumar et al., 2016) shows that hybridization of kevlar and basalt fiber reinforced polypropylene had improved the tensile modulus of elasticity compared to plain kevlar and basalt composites; however, these had not affected the tensile strength of plain kevlar but improved the strength of plain basalt composites. Nevertheless, this hybridization improved the compressive strength and modulus compared to the base composites.

Hybrid composites have increased use in high-tech applications (Kedar S. Pandya, Jayaram R. Pothnis, G. Ravikumar, 2013). One of the applications of hybrid composites is as an amphibious aircraft float material. For the scope of Indonesia, the development of float material made of composite is new and so far there has not been an agreement on a composite that meets the requirements as a floating material. Amphibious aircraft operating in Indonesia use aluminum floats which are sensitive to corrosion when operating in a marine environment and are foreign production aircraft. So it is necessary to know the mechanical properties of the composite that will be used as a corrosion-resistant float material regarding the float material made of aluminum.

In this paper, a study of tensile, shear, and compressive properties was carried out on carbon-based hybrid composites. The objective of this paper is to obtain a hybrid composite material as an alternative to float material. The potential invention from this study is to obtain suitable material for amphibious aircraft floats. This present study utilized woven cloth e-glass fabric and carbon twill 2x2 fabric for glass/carbon hybrid composites; and carbon twill 2x2 fabric and hybrid kevlar-carbon fabric for kevlar-carbon/carbon hybrid composites. This study uses vinyl ester resin as the matrix, due to limited literature on hybrid composites using it. The properties of tensile, shear, compression, and characteristics of microstructural failure are observed.

2. Materials and Methods

2.1. Materials

The reinforcement used in this study is woven roving carbon fabric and woven cloth e-glass fabric for glass/carbon hybrid composites; and woven roving carbon fabric and hybrid woven roving kevlar-carbon fabric for kevlar-carbon/carbon hybrid composites. The carbon fiber used in this study was 2/2 twill, 220 gsm, thickness 0.3 mm, warp and weft density 5.5 thread/cm. The e-glass fiber used in this study was 135 gsm, thickness 0.13 mm, and warp and weft density 9 ends/cm commercially named EW-135 cloth. The hybrid kevlar-carbon (KC) fiber used in this study was 1100D red kevlar and 3K carbon fiber mixed fabric with 200 gsm density and 2x2 twill weave structure. The vinyl ester resin of Bisphenol A, hardener of methyl ethyl ketone peroxide, and promoter of cobalt naphthenate were used as matrix material. The 3% and 0.3% of hardener and promoter were used respectively. Ripoxy R-802 EX-1, Mepoxe, and P-EX are the commercial name of vinyl ester resin, hardener, and promoter respectively. According to the manufacturer statement, Ripoxy R-802-EX-1 is vinyl ester resin for corrosion-resistant FRP production, manufactured by Showa High Polymer Co., Ltd, Japan. These materials are used to fabricate hybrid composites using the vacuum-assisted resin infusion (VARI) method.

2.2. Composites Fabricating

The composites were fabricated using the VARI method. There are e-glass/carbon and kevlar-carbon/carbon hybrid composites. The e-glass/carbon hybrid composites consist of 10 layers of e-glass and six layers of carbon fibers. The stacking sequence is symmetrical and the type of laminate arrangement is $[G/C/G_2/C/G_2/C]s$. The KC/carbon hybrid composites consist of six layers of carbon fibers in the center of laminates and four layers of KC fibers in the outer layers of laminates. The stacking sequence is symmetrical and the laminate type is $[(KC)_2/C_3]s$.

The VARI method utilizes a vacuum pressure from a vacuum pump to flow resin to the laminated area of the fibers. When the vacuum condition has been reached, the resin is flowed from the resin reservoir through the inlet tube to the laminate area until the fiber area is completely wetted. Keep the vacuum condition until the resin gel. The composites panels were cured at room temperature for 24 hours. The fiber volume fraction of glass/carbon composites is 51%, consisting of 18% e-glass and 33% carbon. The fiber volume fraction of KC/carbon composites is 49%, consist of 22% KC and 27% carbon. The test samples were cut from composites panels according to recommendation dimensions of ASTM standards. Afterward, the samples were post-cured at 120 ^{0}C for 3 hours in an oven. The density of glass/carbon and KC/carbon hybrid composites is 1.56 g/cm^3 and 1.34 g/cm^3, respectively.

2.3. Mechanical Test

The mechanical test for tensile, shear, and compression was determined using 100 kN Tensilon RTF 2410.

2.3.1. Tensile Test

The tensile test was conducted according to ASTM D3039 standard. The sample size was 2.5 mm thickness, 25 mm width, and 250 mm length. The constant crosshead speed was used of 2 mm/min through the test. The tensile properties were recorded using a computerized universal testing machine. There are five samples of each hybrid composite.

2.3.2. Shear Test

The In-plane shear tests have been investigated as per ASTM D3518. The sample size (length x width x thickness) was 250 mm x 25 mm x 2.5 mm. The fiber orientation was ±45^0 according to the ASTM standard. There are five samples for each hybrid composites and the shear properties values were evaluated.

2.3.3. Compressive Test

The compressive tests were determined according to ASTM D6641 standard (ASTM, 2001) using a compressive test fixture. The sample size (length x width x thickness) was 140 mm x 13 mm x 3 mm. There are seven specimens of each hybrid composites and the compressive properties were investigated.

2.4. SEM (Scanning Electron Microscopy) Observations

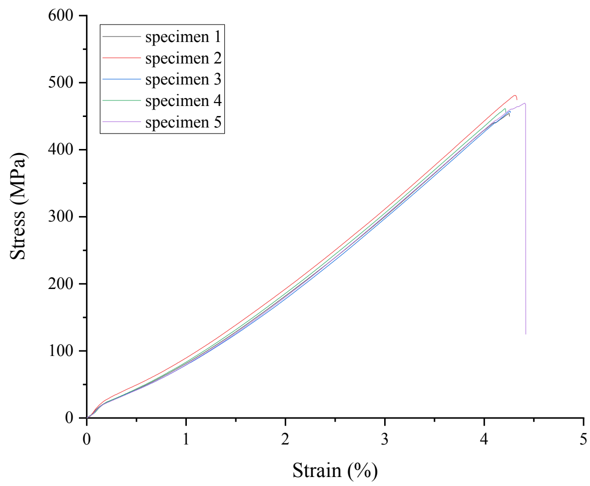
The fracture micrograph was observed by SEM. SEM was performed to evaluated interfacial characteristics of the fracture surface of the composites. It was conducted in the research and test facility of CMPFA (center for materials processing and failure analysis) Universitas Indonesia using FE-SEM FEI INSPECT F50.

3. Result and Analysis

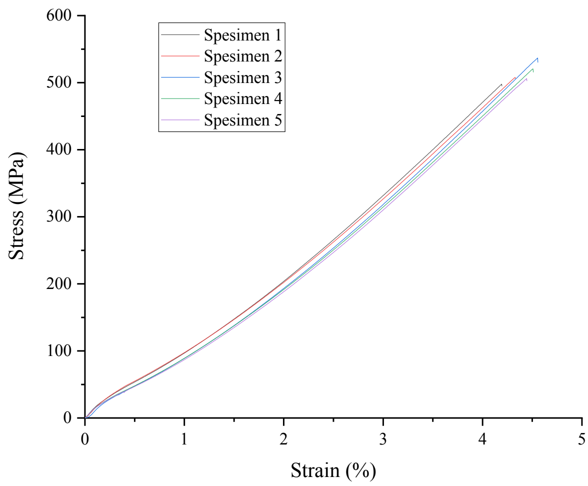
3.1. Tensile Properties

Figure 3-1 (a) and (b) show the tensile strain versus the strength of glass/carbon and KC/carbon hybrid composites, respectively. Fig. 1 shows the tensile strength of KC/carbon hybrid composites slightly higher than glass/carbon hybrid composites. KC fiber in carbon hybrid composites makes the tensile strength higher than glass/carbon hybrid composites.

The tensile strength of glass/carbon and KC/carbon is 465 ± 12 MPa and 516 ± 17 MPa, respectively. This result is similar to previous studies where the tensile strength of KC/carbon composites is higher than glass/carbon although the nominal is different. It means that the tensile strength of KC/carbon higher than glass/carbon up to 11%. When compared with aluminum which has been used as a floating material with a tensile strength of 310 MPa, these two hybrid composite materials have the potential to replace aluminum because their tensile strength is higher than 50%. KC/carbon hybrid composites have higher potential because of their higher tensile strength than glass/carbon.



(a)

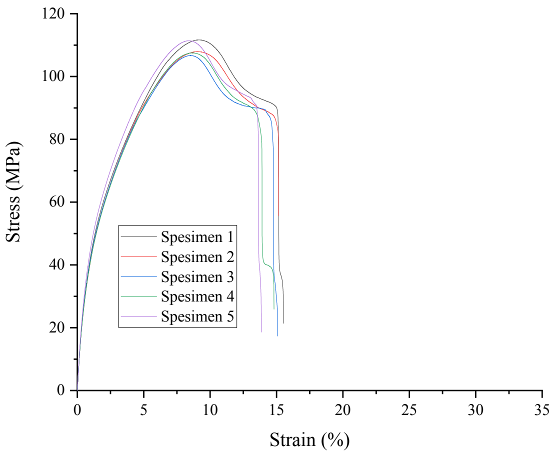


(b)

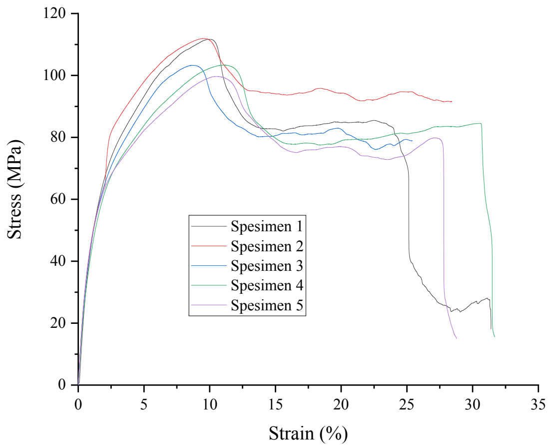
Figure 3-1: Tensile curve of (a) glass/carbon and (b) KC/carbon hybrid composites

3.2. Shear Properties

Figure 3-2 (a) and (b) exhibits the shear curve of glass/carbon and KC/carbon hybrid composites recorded by a universal testing machine. The experimental results exhibit that the shear properties of glass/carbon and KC/carbon hybrid composites are typically similar. The ultimate shear strength of KC/carbon (105 ± 5 MPa) is 4% lower than glass/carbon (110 ± 3 MPa). This result is similar to previous studies where the shear strength of KC/carbon composites is lower than glass/carbon although the nominal is different. It indicates there are no significant differences in shear properties observed between these hybrid laminate composites, although the placement of KC and glass fibers is different in each composite. When compared with aluminum which has been used as a floating material with a shear strength of 207 MPa, the two-hybrid composite materials have a shear strength below the shear strength of aluminum. So that both of these materials need to be increased in shear strength or applied to floating structures that are subject to shear loads below their ultimate shear strength.



(a)

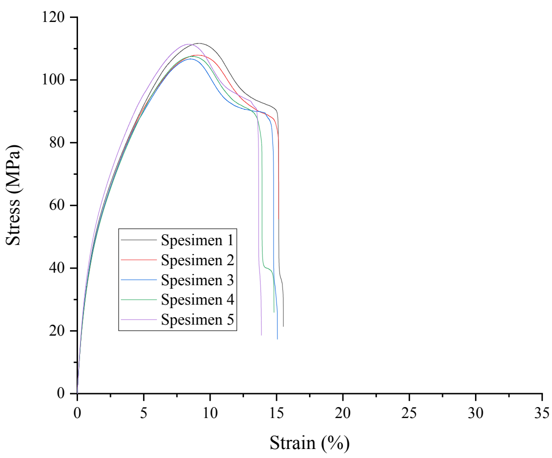


(b)

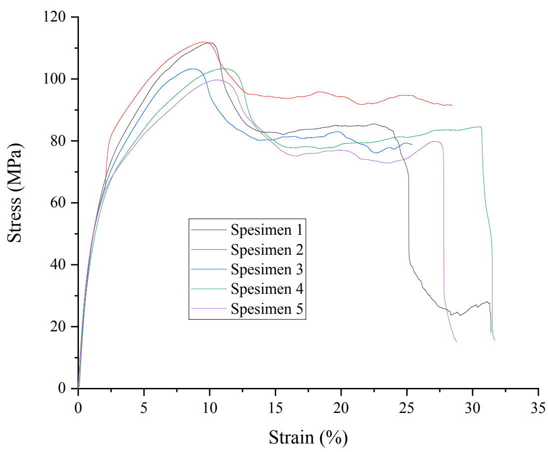
Figure 3-2: Shear curve of (a) glass/carbon and (b) KC/carbon hybrid composites

3.3. Compressive Properties

Figure 3-3 (a) and (b) exhibits the compressive curve of glass/carbon and KC/carbon hybrid composites, respectively. Fig. 3 shows that the compressive strength of KC/carbon is slightly higher than glass/carbon hybrid composites. The compressive strength of KC/carbon is higher than glass/carbon up to 9%. The compressive strength is 245 ± 9 MPa for glass/carbon, and 267 ± 25 MPa for KC/carbon respectively. This result is similar to previous studies where the compressive strength of KC/carbon composites is higher than glass/carbon although the nominal is different. There are only small differences in compressive properties of both hybrid composites despite the addition of different types and arrangement of fibers into the laminates. When compared with aluminum which has been used as a floating material with a compressive strength of 234 MPa, the two-hybrid composite materials have a higher compressive strength than the compressive strength of aluminum. So that these two materials have the potential to replace aluminum as an amphibious aircraft float material. KC/carbon composites have higher potential because of their higher compressive strength than glass/carbon.



(a)



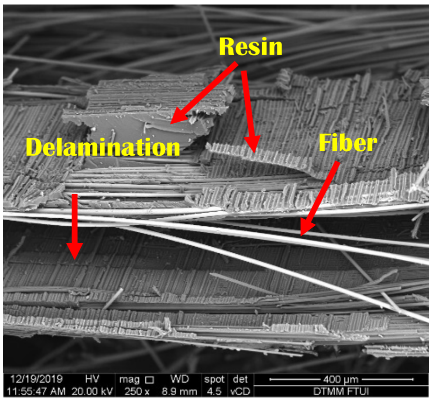
(b)

Figure 3-3: Compressive curve of (a) glass/carbon and (b) KC/carbon hybrid composites

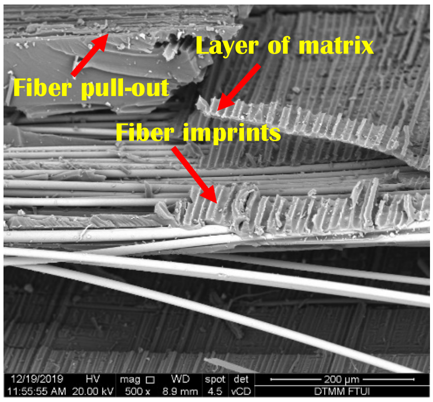
3.4. SEM

The cross-section characteristics of composite fractures were observed using SEM. SEM was performed on the fracture surface of the tensile test specimen. Figure 3-4 (a, b) and (c, d) exhibit the SEM micrograph of glass/carbon and KC/carbon hybrid composites. It is observed that glass/carbon and KC/carbon hybrid composite have different modes of failure. Delamination, fiber imprint, and fiber pull-out are the major modes of failure for glass/carbon composites. It is consistent with to study of woven roving fiber composites that shown these modes of failure (R. Kumar & Chandra, 2018). The fiber pull-out and fiber imprint modes of failure are associated with poor fiber/matrix bond, and the delamination is related to poor bond between the layers of carbon and glass fibers. The poor fiber/matrix bonds and the bonds between layers cause the strength of this composite to be lower than that of KC/carbon composites.

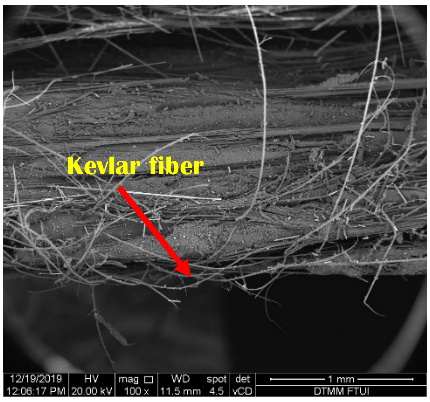
The SEM results show the different failure characteristics of KC/carbon hybrid composites. Fig. 3-4 (c) shows kevlar fiber after failure in the fibrous-form different from glass and carbon fibers. The surface fracture micrograph shows the good fiber/matrix of KC/carbon composites as can be seen in Fig. 3-4 (d). There is no delamination observed in the fracture micrograph of KC/carbon hybrid composites. It exhibits that the KC/carbon has a good fiber/matrix and interlayer bond better than glass/carbon hybrid composites. Good fiber/matrix bonds and bonds between layers cause the strength of this composite to be higher than glass/carbon composites.



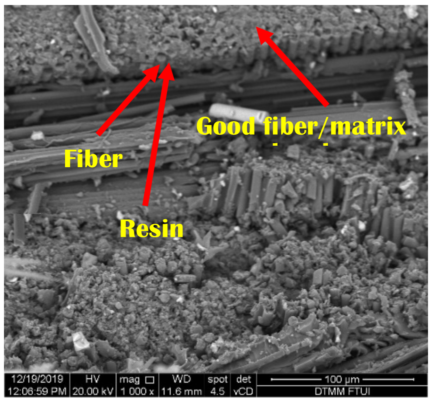
(a)



(b)



(c)



(d)

Figure 3-4: SEM micrograph of (a),(b) glass/carbon and (c),(d) KC/carbon hybrid composites

4. Conclusions

The results of the study in this paper show that the composite material which has the most potential as an amphibious float material is the KC/carbon hybrid composites. This is based on the results of studies that show the tensile and compressive strength of KC/carbon composites is higher than aluminum and higher than glass/carbon hybrid composites. In addition, the fiber/matrix and inter-layers bond is also better than glass/carbon composites.

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Contributorship Statements

KA is the main contributor and MA is the second contributor.

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