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FRP선박의 범용 재활용을 위한 재처리시스템의 연구

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Developing a General Recycling Method of FRP Boats

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요 약

FRP선박의 폐처리와 재활용 연구는 지난 10여 년간 많은 발전이 이루어져왔다. 특히 해상용과는 달리 폐기물의 투기나 방치가 매우 어려운 육상용 폐FRP의 재활용 방법과 기술의 발전에 기인한 결과이기도하다. 따라서 가장 많은 폐FRP 선박의 재처리는 육상용의 처리공정, 즉 파쇄와 분쇄 공정을 거친 후 수지류와 유리섬유류로 분리하여 재활용 또는 지정폐기물로 처리하게 되었다. 지난 연구를 통하여 처리공정 운영 측면에서 보다 경제적이며 2차 처리공정(분쇄 후 공정)에 유용한 시스템을 개발하였다. 그러나 다년간의 실험실규모의 처리시스템 운영을 통하여 두 가지의 개선점이 발견되었다. 첫째는 단순 용융하여 활용하던 유리섬유의 형상(폭과 넓이)의 다양화가 필요하게 되었으며, 두 번째 문제로는 수중 파쇄 공정 도입을 통하여 분진을 억제하였으나 시스템 상부(파쇄전 공정)를 통한 분진유발로 인하여 작업성의 저하가 발생한다는 것이다. 우선 유리섬유의 형상변화는 파쇄공정 중 칼날의 변화를 통하여 섬유 형태뿐만 아니라 chip형태(직사각형)로 박리할 수 있게 되었으며 파쇄공정의 상부에 cyclone분류기를 설치하여 유리가루와 수지가루를 분류하여 재활용하게 되었다. 아울러 작업환경의 청정성도 유지하게 되었다. 또한 유리chip을 활용한 2차 콘크리트 제품의 강도 실험결과 매우 우수한 결과를 보여주고 있으므로 앞으로의 폐FRP 선박의 재활용 분야의 다양성을 기대할 수 있을 것이다.

Abstract – For several decades, many researchers have been involved in developing recycling methods for FRP boats. There are four basic classes of recycling covered in the literature. Despite of environmental problems (safety hazards), mechanical recycling of FRP boats, which involves shredding and grinding of the scrap FRP, is one of the simpler and more technically proven methods than incineration, reclamation or chemical ones. Because FRP is made up of reinforced fiber glass, it is very difficult to break into pieces. It also leads to secondary problem in recycling process, such as air pollution and unacceptable shredding noise level. Another serious problem of mechanical FRP recycling is very limited reusable applications for the residue. This study is to propose a new and efficient method which is more wide range applications and environment friendly waste FRP regenerating system. New system is added with the cyclone sorting machine for airborne pollutions and modified cutting system for several glass fiber chips sizes. It also has shown the FRP chip fiber-reinforced concrete and fiber-reinforced secondary concrete applications with the waste FRP boat to be more eligible than existing recycling method.

Keywords: FRP Recycling(섬유강화플라스틱의 재활용), Waste FRP Boat Regenerating(폐FRP선박의 재자원화), Eco-friendly Mechanical FRP Recycling(환경친화적/기계적 FRP재활용), Recycled FRP fiber-reinforced concrete(재활용 유리섬유를 이용한 콘크리트제품)

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1. INTRODUCTION

Many methods for recycling waste FRP boats have been developed. There are four basic classes of recycling covered in the literature (Shoji[2003], Defosse[2003], Bartholomew [2004], EuCIA, [2005, Jang *et al.*[2006]). First, mechanical recycling are shredding and grinding of the scrap FRP in a new product. The others are "Incineration combustion" of FRP scrap with energy or "Thermal recycling" of FRP scrap and "Chemical method of recycling" using chemicals to dissolve the resin away from the fibers. The last is combining those methods for each step in the whole recycling process. Despite of the safety hazards, mechanical recycling is one of the simple and technically proven methods. In which, recent researchers (Nakagawa[1998], Fukada and Zairyo[2006], Shibata and Zairyo[2006], Yoon[2007]) should be more interested in these methods. While the effort has been made in mechanical recycling the FRP used for the medium-to-small size ships, researchers (Whang *et al.*[2002], Yoon *et al.* [2007], Yoon[2007]) try to find out the methods more favorable for the environments and more value-added. In respect to the fact that the FRP consists of two types of layers, roving cloth and fiber glass mat, differentiated by the 2-dimensional structure, our group was able to separate the layers of FRP instead of grinding it. The roving cloth could be cut to the chips (about 8×8 or 16×16 mm) and residue in Fig. 1. These glass fiber chips showed increasing tensile and bending strength and chemical-resistance possibly due to the remained resin (about 25% by weight). In this experiment fiber-reinforced mortars and FRC product are made of the glass fiber chips from a new recycling system of waste FRP boats. These results imply that recycled glass fiber can be applied to the 'fiber reinforced mortar/concrete' and furthermore the process may be new eco-friendly FRP regenerating system to the waste FRP boats.

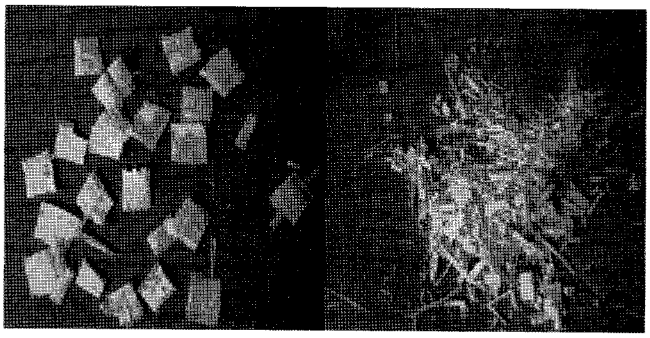


Fig. 1. The FRP glass fiber chips and residues.

2. ECO-FRIENDLY RECYCLING METHODS

The new recycling system (Yoon[2007]) is a total commitment to the evolution of water-based shredding optimization (evolution with optimal angle) (Fig. 2), smashing through the water, and capable of scaling (8 mm and 16 mm or a certain size). In addition, due to the power-saving effects and reducing noise and dusts (totally enclosed structure, and improved shredding mechanism), new recycle system enhanced economic efficiency and eco-friendly character.

2.1 Old Shredding Mechanism

Fig. 2 is a fair bulk of the full recycling system. Noise and dusts are reduced favorably due to isolate slots in the closing run. All of the open portions of the system are sealed to prevent passing the dust and noise out. Directly under the blade, the circulated water facilitates this process and inhales the dust into the pipe to prevent from emitting out (Fig. 2 - ①, ②). Inside the pipe a rotated screw mixes chips with water, preventing also dust and glass/resin powder scattering out (Fig. 2 - ③). If the application of recycled FRP is a polymer cement, the powder by shredding the FRP which is composed of two kind of materials-glass and resin, should be separated fully. The separation between the resin and glass fiber scraps is preceded in tank 1 (Fig. 2 - ④, ⑤, ⑥), the next step separation in tank 2 is between resin and glass powder, which is very effective process for regenerating the FRP waste.

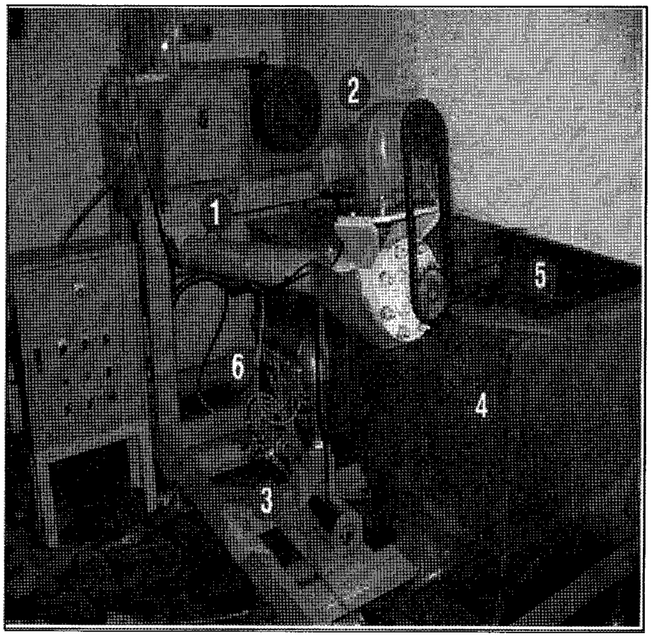


Fig. 2. Existing total crushing system.

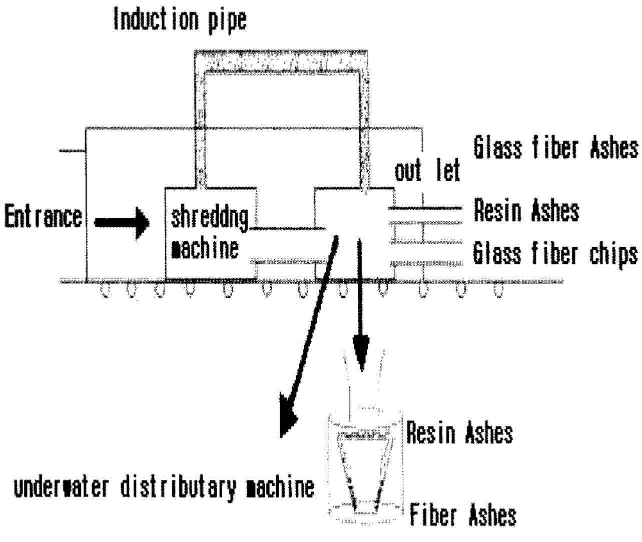


Fig. 3. Total FRP recycling system with cyclone sorter.

2.2 Development of New Recycling System

The process of total crushing system has a cutting part, a compound sorting part and a pollution isolating part.

To increase efficiency and regenerations of recycling FRP boats, disjointing crusher operation should require eco-friendly and regenerating operations. Fig. 3 shows new recycling FRP boats process which also indicates the total process considered (Yoon[2007]). New system will be added with anti-airborne pollutions part and flexible cutting system in Fig. 4.

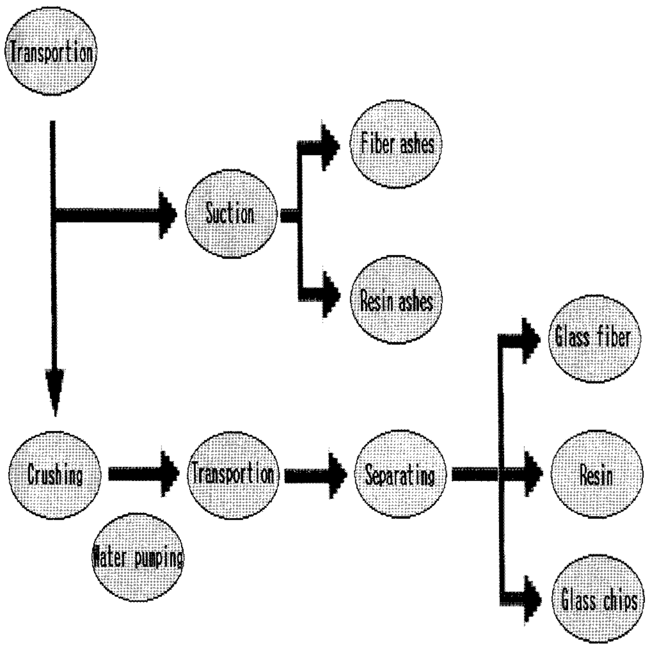


Fig. 4. Total recycling system of waste FRP boats.

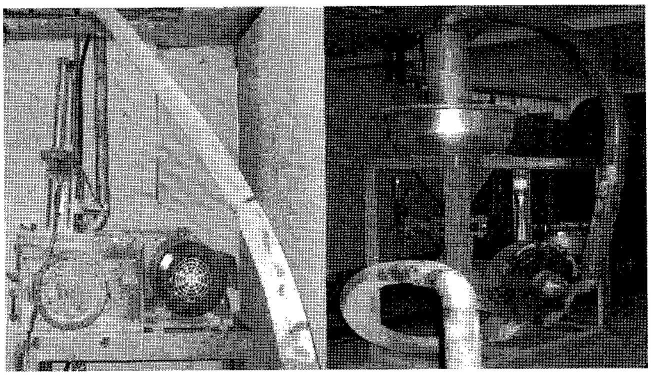


Fig. 5. Cyclone sorting machine.

3. EXPERIMENT OF FRP CHIPS REINFORCED CONCRETE

3.1 Physical Properties of FRP Chips Reinforced Concrete (boundary stones)

FRP chips are obtained from roving cloth of the matrix form in waste FRP, FRP chips are two sizes (8×8 or 16×16 mm). FRP chips with some resin coated was compared with polyvinyl fiber (for FRC) and virgin glass fiber (Yoon *et al.* [2007]). But this study is applied for general usages such as boundary stones (KS F 4419) and water pipe (bench hume pipe, KS F 4010). Because the wide range of usage of recycled FRP waste could be a sustainable regenerating system.

Table 1 shows the condition of boundary stones applications. Each experiment are performed for six times for reliable data.

The physical properties of FRP chips concrete were measured in Table 2. The result of tests indicated that the substance of FRP chips for the concrete were very acceptable in the point of strength, specially bending strength which was essential property of boundary stones (Fig. 6-8). Also the substance should reduce the weight of concrete about

Table 1. The condition of sample test with FRP chips.

	Case1	Case2	Case3 (plain products)
Sand	18 kg	18 kg	18 kg
Stone aggregates	12 kg	12 kg	12 kg
Cement	3.3 kg	3.3 kg	3.3 kg
Glass fiber(chips)	0.5 kg	0.5 kg	0
Water	1.1 kg	1.1 kg	1 kg
Water/cement ratio	33.3%	33.3%	30.3%
Number of test sets	6	6	6

case1: 8×8 mm - FRP chips(cement ratio to 15% ratio) inserted
case2: 16×16 mm - FRP chips(cement ratio to 15% ratio) inserted

Table 2. The physical properties of boundary stones with FRP chips.

Specimen NO	Bending Strength (MPa)			Compressive Strength (MPa)			Water absorption factor (%)	Weight (kg)
	4days	14days	18days	4days	14days	18days		
Case1	28.68	34.57	44.43	16.3	61.23	65.66	4.9	1.97
Case2	21.28	31.91	42.38	12.3	48.6	54.85	6.8	2
Case3	25.36	32.91	44.23	17.3	79.22	88.19	4.6	2.11

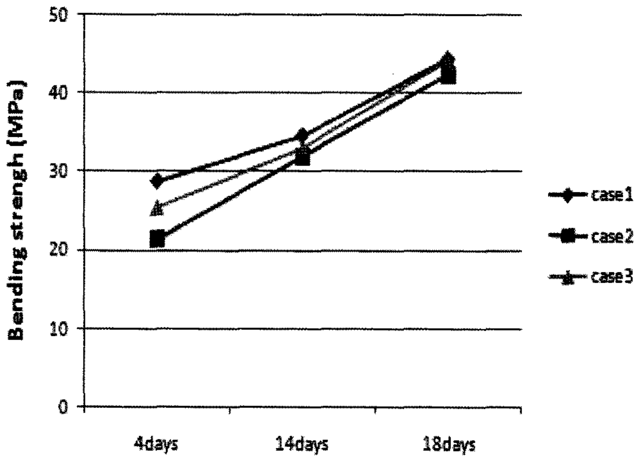


Fig. 6. Bending strength of the concrete containing various amounts of FRP chips.

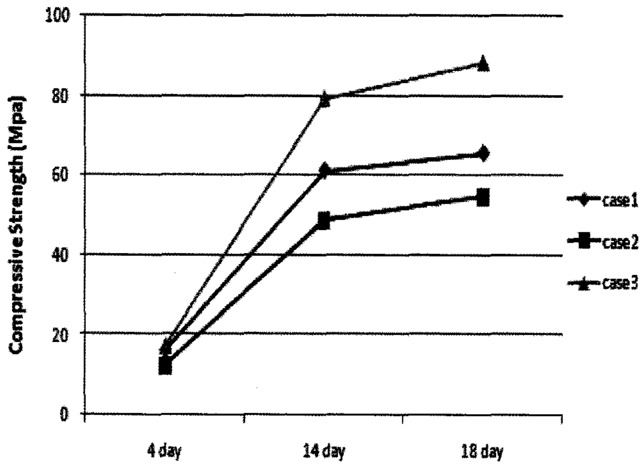


Fig. 7. Compressive strength of the concrete containing various amounts of FRP chips.

10%, which was another good reason for the usage of FRP waste in Fig. 9.

FRP chips tensile strength were showed in Fig. 10, which has enough strength not to separate even after yielding failure point.

One aspect of the four-day routines indicated that the cured concreter has indicated to the fibers separated, but 18 days after, the fibers had enough holding strength not breaking down (Fig. 10).

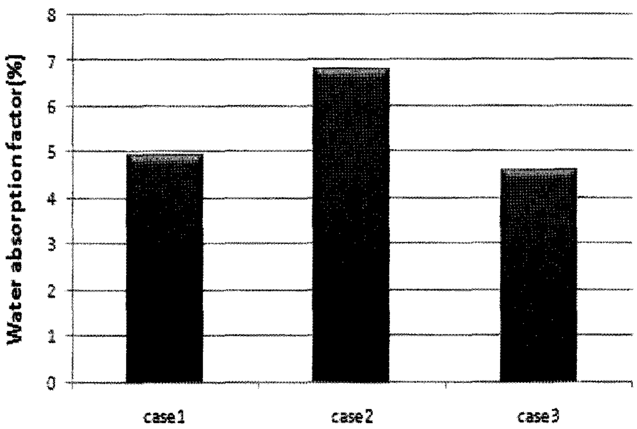


Fig. 8. Water absorption of the concrete containing various FRP chips.

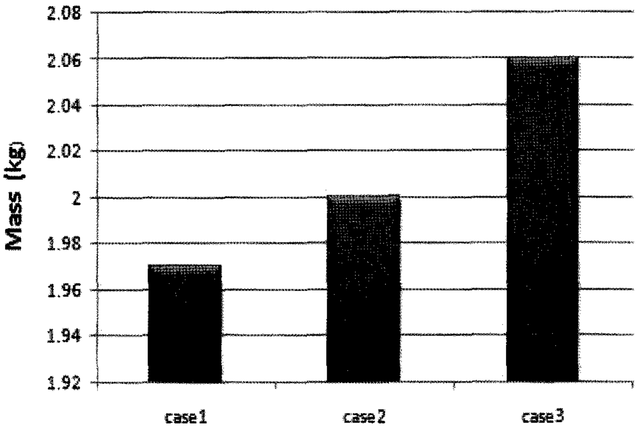
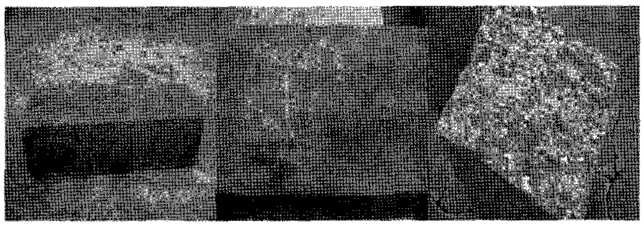


Fig. 9. Mass of the concrete containing various FRP chips.



(a) (b) (c)

Fig. 10. Photos of boundary stones containing 3% glass chips for (a) a plain (b) with FRP chips (c) bisected concrete with chips.

3.2 Physical Properties of FRP Chips Reinforced Concrete (bench hume pipe)

There are two types of glass-chips from the new recycling FRP system. The chips were two sizes, 8×8 mm and

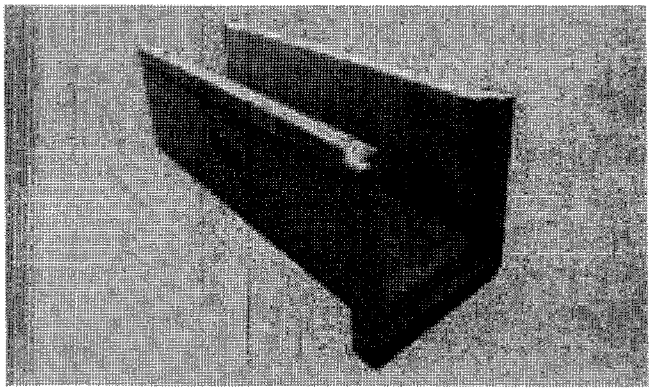


Fig. 11. The concrete product (water pipe) for full scale test.

Table 3. The condition of sample test with FRP chips of water pipe.

	Case1	Case2	Case3	Case4 (Plain products)
Sand	581 kg	581 kg	581 kg	581 kg
Aggregate	12 kg	12 kg	12 kg	12 kg
Cement	257 kg	257 kg	257 kg	257 kg
Glass chips	2.57 kg	0 kg	1.29 kg	0 kg
Water	108.8 kg	106.8 kg	108.8 kg	99.8 kg
Fiber powder	0 kg	2.57 kg	1.29 kg	0 kg
The water/cement ratio	42.33%	41.56%	42.33%	38.83%

case1: cement ratio to 1% with FRP chips inserted
case2: cement ratio to 1% with powder inserted
case3: cement ratio to 1% with FRP chips and powder inserted

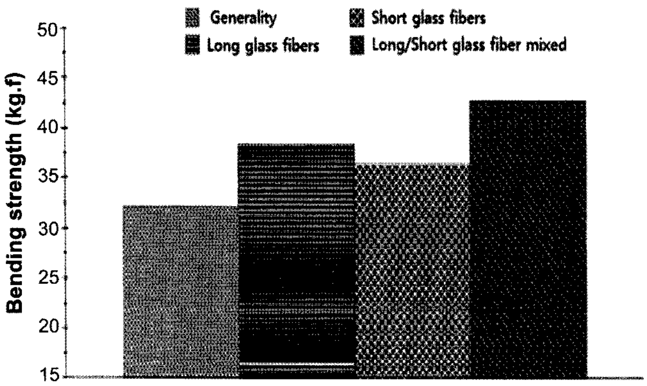


Fig. 12. The result of bending strength test of sample size with glass-chips.

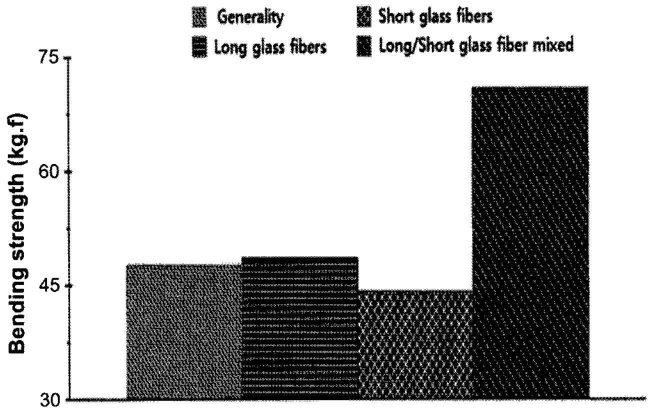


Fig. 13. The result of bending strength test of bench hume pipe with glass-chips.

16×16 mm. The other one was fiber residues (powder). The full scale experiments were tested for both types of recycled FRP chips and FRP powder. The result showed the glass-chips to be a regenerated material.

In new recycling system of the waste FRP, FRP chips are extracted from FRP. The FRP chips are applied to FRC products (sample size). The results of strength tests are as follows. In sample size test both materials (chips, powder and compound) showed better results even though within 10% range in Fig. 12. Then the advanced experiment were performed successively. Table 3 as a full scale production shows a test conditions in the experiment which has been used in traditional secondly concrete product (water pipe, Fig. 11).

Fig. 13 shows that the bending strength of the concrete with waste FRP compounder is exceptional though the one with powder was decreased, but still was to be in permissible range. That also shows a great possibility to use FRP chips into FRC for the secondary concrete product which has major concern with bending strength.

4. CONCLUSIONS

1. New proposed mechanical recycling system is not just efficient but also eco-friendly waste FRP regenerating system. It remarkably reduces safety hazards (air pollution and shredding noise) and crushing energy. Using the mechanical properties of polymers and composite, FRP with the orthotropy and laminated plastic structure can be easily scrapped in the new shredding system.

2. The FRP chips can be extracted as several sizes which is equivalent to high-cost commercial fiber to increase strength of concrete. The result of sample and full scale test have shows the effectiveness of the FRP chips which is also chemical-resistant due to the resin coating.

3. The application of FRP chips FRC-product is to be very effective and value added. The concrete product with glass-chips is to increase compressive and bending strength and reduce weight and production cost compared with the commercial fiber.

ACKNOWLEDGMENT

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