Assembly Automation

Study of shape memory polymers snap-fit for disassembly

Hua Li Javier Ortega Ying Chen Bang He Kai Jin

Research article

Study of shape memory polymers snap-fit for disassembly

Hua Li
Mechanical and Industrial Engineering Department, Texas A&M University-Kingsville, Kingsville, Texas, USA

Javier Ortega
Pharr-San Juan-Alamo High School, San Juan, Texas, USA, and

Ying Chen, Bang He and Kai Jin
Mechanical and Industrial Engineering Department, Texas A&M University-Kingsville, Kingsville, Texas, USA

Abstract

Purpose – The purpose of this paper is to investigate the effects of different shape memory polymer based snap-fits in terms of disassembly time and reusability.

Design/methodology/approach – In total, six different sets of snap-fits were designed and manufactured. Each set of snap-fits was tested ten times in a testing device for disassembly time. The stress caused by training process is simulated and analyzed.

Findings – One of the designs shows shortest average disassembly time, lowest standard deviation, and lowest stress. However, the overall reusability of the snap-fits is not good enough for industrial use.

Originality/value – The paper tests the Veritex shape memory polymer sheets manufactured by CRG Industries LLC. The reusability has been analyzed based on the stress caused by the training process.

Keywords Polymers, Stress (materials), Snap-Fit, Disassembly, Shape memory polymer

Paper type Research paper

1. Introduction

Recycling is a key component of modern waste reduction. Nevertheless, high cost restricts the number of products to be recycled. Much of the research that aims to improve the flexibility and efficiency of disassembly operations has been on design methodologies that incorporate simple and efficient disassembly mechanisms. The most basic of these methodologies is design for disassembly (DfD) that relies on easily released fasteners within product assemblies, proper handling operations, and standardized designs for flexible and efficient disassembly operations (Boothroyd and Alting, 1992). Because the one-to-one disassembly process of DfD has limitations according to the number of fastening elements within the design, the one-to-many disassembly process has introduced two methodologies: disassembly embedded design (DED) and active disassembly (AD) (Sodhi and Knight, 1998). DED relies on specialized disassembly mechanisms within the product's design. Conceptual designs for DED have shown efficiency improvements in disassembly processes, but due to their specialization for each product, intense work in the design stage is needed, which limits DED's flexibility and use (Duflou *et al.*, 2006). In an effort to reduce this design work and increase flexibility, AD has resulted. Unlike DED, AD relies on generic fastening elements, which can be easily incorporated into existing designs with little to no added design effort. This general application of such elements has created the flexible and efficient disassembly processes needed to make disassembly a more economically viable end of life (EOL) activity (Duflou *et al.*, 2006). The use of active disassembly based on smart materials (ADSM) can be an alternative, with the potential to enable a broad range of electronic devices to be actively disassembled at the same time, and to reduce the cost of the manual labor or machine operation needed in traditional disassembly process (Chiodo *et al.*, 1998a, 1999). Electronic manufacturers can integrate smart materials in the product design, ensuring that the product contains the necessary mechanisms to disassemble by itself using an external stimulus as a trigger at its EOL stage. As reviewed by Spillman *et al.* (1996), there are two major types of smart materials that have been incorporated into AD: shape memory alloys (SMAs) and shape memory polymers (SMPs).

The shape memory effect (SME) is the special characteristic that SMPs have to recover large strains deformations upon an

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external stimulus (Duflou *et al.*, 2006; Chiodo *et al.*, 1998b). SMPs are polymers, with a special chemical composition that gives them the "shape memory" property. The SME requires two components: cross links, which determine the permanent shape, and "switching segments" which determine transition temperature (T_{trans}) to maintain the temporary shape (Lendlein and Langer, 2002). SMPs are stiff below T_{trans}. They will be relatively soft upon heating above T_{trans}, and consequently be deformed into a desired temporary shape by applying an external force. When SMPs cool down and external force is removed, the temporary shape can be maintained. Upon heating again, the temporary (deformed) shape will change to the original permanent shape. SMPs can be activated by heat (Ji *et al.*, 2006), magnetism (Mohr *et al.*, 2006), electricity (Cho *et al.*, 2005), light (Lendlein *et al.*, 2005), moisture (Huang *et al.*, 2005), and even some chemical stimulus (Leng *et al.*, 2011). A number of ADSM elements have been conceptually designed and analyzed, and the use of smart materials has been extensively documented, such as SMP used in thread-losing screws and deformable brackets (Chiodo *et al.*, 1999, 2000). One of the advantages of those SMP based ADSM elements is reducing disassembly time and cost for large batch product disassembly (Chiodo and Boks, 1999, 2002). However, due to the required training process for restoring SMP back to assembly position after disassembly, the reusability of those SMP based ADSM elements is relatively poor because of the residual stress caused during the training process.

In this paper, the authors investigate the effects of different designs of SMP based snap-fits by comparing their disassembly time and reusability. Six different sets of snap-fits were designed and manufactured. Each set of snap-fits were tested ten times in a testing device for recording disassembly time. The stress caused by training process is simulated and analyzed.

2. Materials and methods

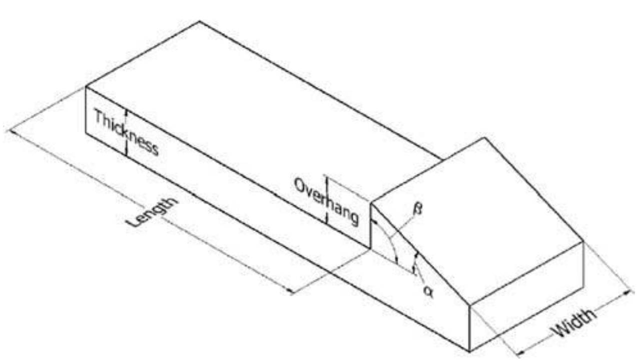
2.1 Materials used and design of snap-fits

Snap-fits joints are common assembly components in many products, which consist of a projecting beam and an overhang. The basic form of a snap-fit is shown in Figure 1. From Figure 1, the basic cantilever snap-fit geometry consists of a thickness, an assembly angle (α), a disassembly angle (β), an overhang, a width, and a length.

The snap-fits using SMPs have two shapes: an assembly shape and a release shape. The assembly shape is a straight snap-fit that allows the overhang to be placed in the housing recess and holds during the assembly or use. The release shape is the shape when the snap-fit is to be disassembled, and it includes a slight bend or release angle at the base of the snap-fit as show in Figure 2.

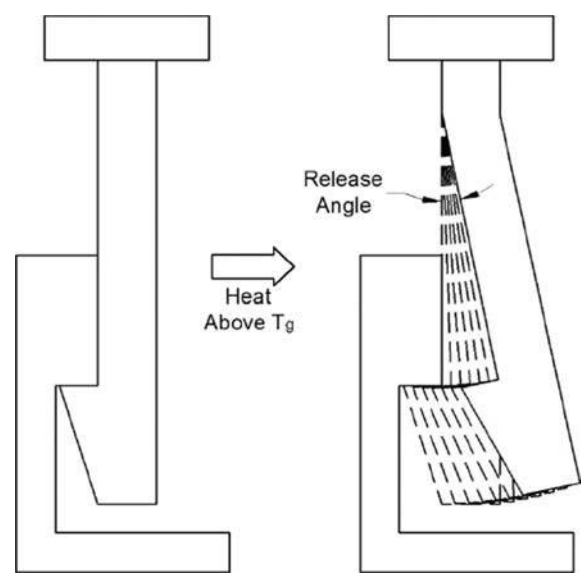
Since the SMP based snap-fit must return to the release position when upon being heated, the release shape was the original shape for the SMP snap-fit (Figure 3). Based on previous research results (Carrell *et al.*, 2011), the release angle and length of overhang were chosen as targeted design parameter to be analyzed in the test. The design parameters of snap-fit prototypes in their release position were chosen according to a snap-fit design handbook (Bonenberger, 2005) and analysis results of various factors during pre-test. The minimum release angle depends on the overhang length, which was chosen according to manufacture limitations. In this project, two overhang lengths (3 and 4 mm) were chosen with three different angles as shown in Table I. Six sets of snap-fits with different design parameters were manufactured from commercial Veritex SMP sheets, developed by Cornerstone Research Group (CRG). Veritex SMP sheets we used are six layers with 3.18 mm in thickness, and the material properties are shown in Table II.

Figure 1 Basic snap-fit geometry



Source: Carrell *et al*. (2010)

Figure 2 Assembly position (left) and disassembly position (right) of a snap-fit



Source: Carrell *et al*. (2010)

Figure 3 Snap-fit design (release position)

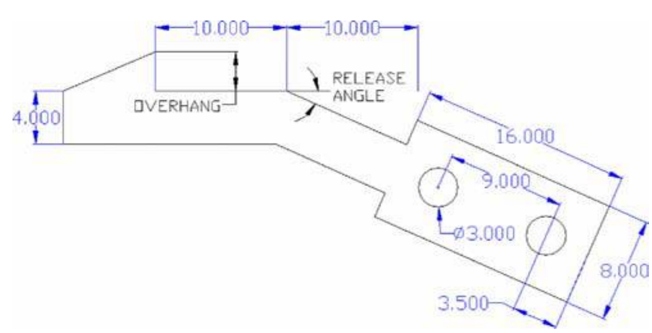


Table I Snap-fits design parameters

Design	Length (mm)	Overhang (mm)	Release angle (°)
Snap-fit 1	20	3	18
Snap-fit 2	20	3	24
Snap-fit 3	20	3	27
Snap-fit 4	20	4	21
Snap-fit 5	20	4	24
Snap-fit 6	20	4	30

Table II Material properties of SMP sheet

Tensile module (MPa)	1227
Tensile strength (MPa)	16.7
Breaking point	0.017
Yielding strength (MPa)	6.135
Yielding point	0.005
Glass transition temperature (T_g)	62°C

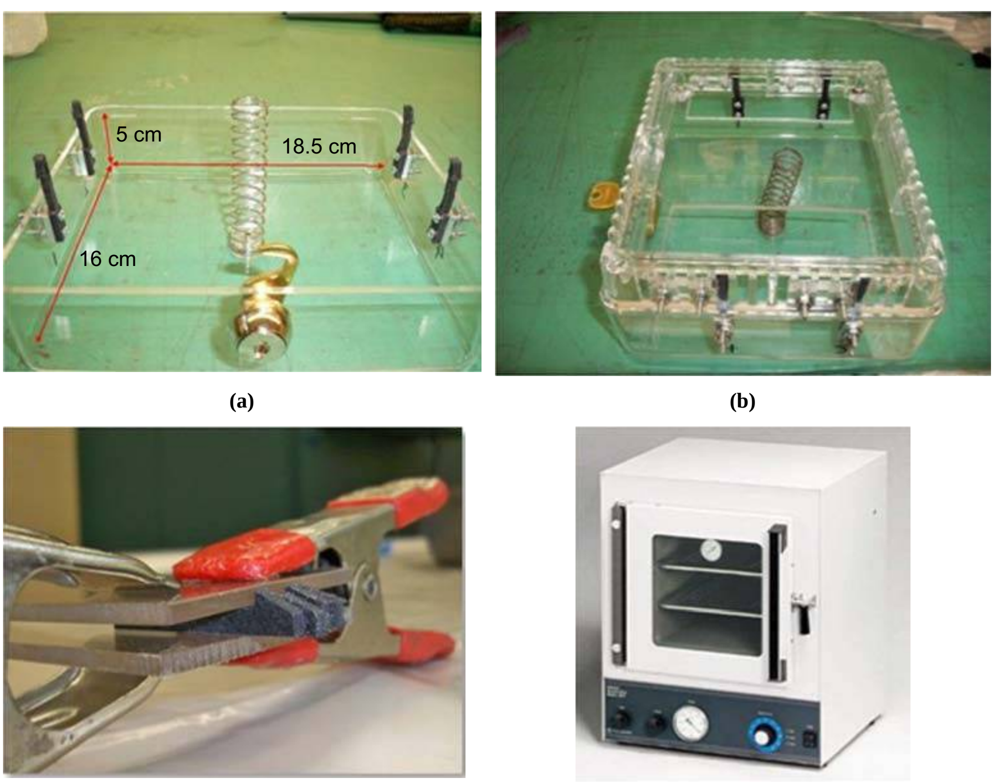
2.2 Testing devices and methods

A testing device was design and modified based on a commercial case for simulating a housing case. The case is a polycarbonate box that is originally used as thermostat guard with removable cover. Dimensions of the box are shown in Figure 4(a). A spring was attached to the center of the box, and the walls were machined in order to attach the snap-fits. The AD tests were carried out in three stages. In the first stage, the SMP snap-fit was heated at 85°C for about 5 min in an electrical oven (Figure 4(d)) in order to train the material and modify its original shape to a temporary shape (assembly position). It was deformed using a couple of tweezers (Figure 4(c)) outside the oven at room temperature about 2 min to achieve its assembly position. The second stage is to assemble or close the testing device using the snap-fits (Figure 4(b)). In the third stage, the testing device was placed inside the oven at 85°C to activate the snap-fits and release the snap-fit joint (Figure 5). We define a successful disassembly process if the cover was ejected by the spring force due to part of or all the snap-fits recover their original shape. During the test, the testing device was continuously monitored by visual inspection through the front door in the oven. The snap-fit training time and disassembly time for each experiment was recorded using a stop watch. During our pre-test, the snap-fits showed failures around the 11th to 15th repetition due to repetitive training process. So we decided to conduct ten repetitions for each set of snap-fits in the test. The entire box was cooled down to room temperature before switching to a new set of snap-fits.

3. Results and discussion

The completed testing results of disassembly time (in second) are shown in Table III.

Figure 4 Testing devices



(a) (b) (c) (d)

Note: (a) dimension of the box, (b) assembled box, (c) training process, and (d) oven

Assembly Automation
Volume 32 · Number 3 · 2012 · 245–250

Figure 5 (a) Assembled testing device inside the oven at the beginning of the test and (b) disassembled testing device, end of the test

(a) (b)

Table III Completed testing results

		3 mm overhang			4 mm overhang		
	Repetition	18°	21°	24°	24°	27°	30°
Time (s)	1	737.4	856.8	747.0	750.6	911.4	869.4
	2	312.6	493.8	255.6	269.4	486.0	247.8
	3	244.8	447.6	215.4	302.4	438.0	506.4
	4	253.2	261.6	251.4	371.4	313.2	428.4
	5	315.0	372.0	334.8	369.6	448.2	606
	6	254.4	313.2	423.0	214.8	564.0	429.6
	7	309.0	310.8	383.4	385.2	384.0	151.8
	8	190.8	312.6	448.8	244.2	430.2	385.8
	9	211.2	266.4	182.4	300.0	565.8	361.8
	10	323.4	304.8	375.6	322.8	572.4	546.6

Since the entire box was in room temperature in the first repetition of testing each set of snap-fits, it needs more time to be heated up compared to the rest nine repetitions. In order to increase the accuracy, we decide to delete the first repetition results for each set of snap-fits in the following calculation and discussion (Table IV).

According to the results, the snap-fits with 3 mm overhang and 18° release angle show the shortest average disassembly time and lowest standard deviation among all the designs. In order to choose the best one among all six designs, reusability is considered as another criterion. The residual stress caused by SMP training process is the major factor affecting snap-fit's reusability. Less residual stress means longer lifespan. The residual stress caused by training process of each design is simulated in NEi Nastran. In the simulation, only isotropic stress was considered for different release angles. In Figure 6, it shows the residual stress will increase when the release angle increases. So the design with 18° release angle will have less residual stress caused by the training process, and its reusability will be better than the other tested designs.

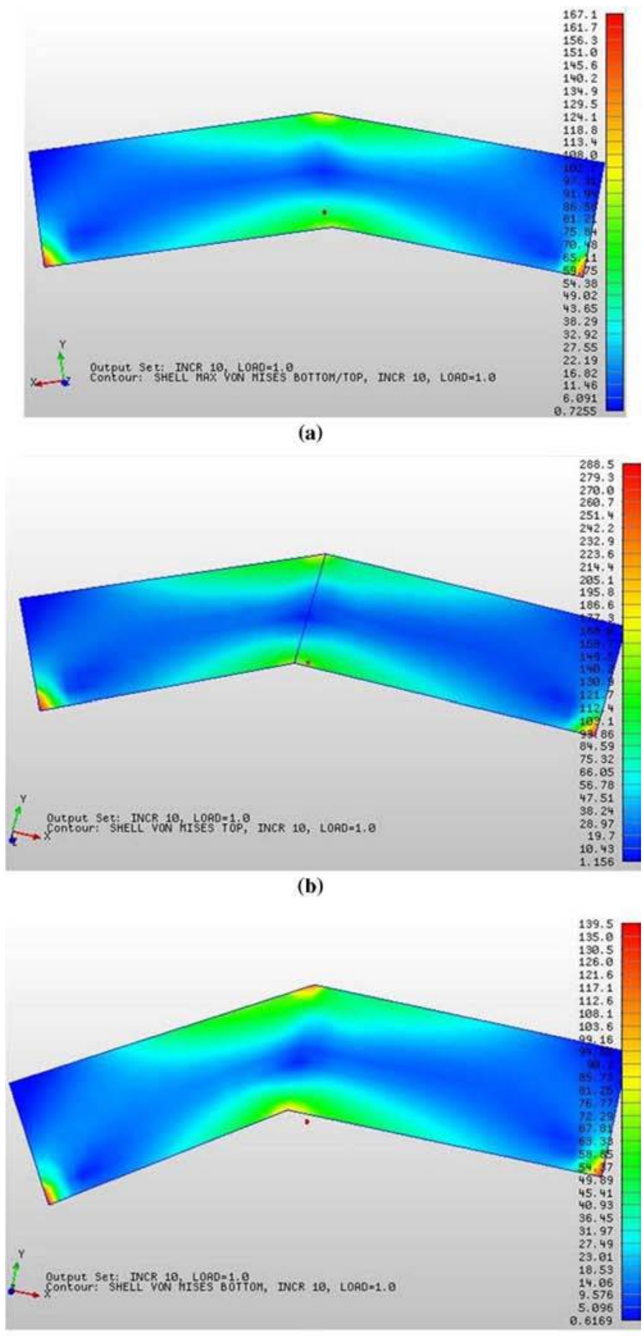
Table IV Average disassembly time and standard deviation without first repetition

Snap-fits Overhang (mm)	Angle (°)	Average disassembly time (s)	SD
3	18	268.3	0.814
3	21	342.5	1.335
3	24	318.9	1.595
4	24	308.9	0.992
4	27	466.9	1.488
4	30	407.1	2.378

4. Conclusion

Considering both disassembly time and residual stress, the design of 3 mm overhang with 18° release angle is the best design among all tested snap-fits. Although the overall reusability of the tested snap-fits is not good enough for industrial applications, choosing the overhang and release angle as smallest as possible will decrease the disassembly time and increase the reusability according to the testing results. In the testing process, several factors have been noticed that may affect testing results. First, the cover of the box is deformed after continuous heating that may affect the accuracy of disassembly time. Second, the authors also noticed that most of snap-fits cannot be 100 percent recovered to their original shape after repetitive heating and training processes. It may be related to the Veritex SMP's material properties. To avoid the affection caused by material itself and compare different SMP materials, more SMP materials should be tested in the future research work. Future work should also focus on increasing the accuracy of results by modifying the time recording methods and testing device. Since the structure failures observed after repetitive testing process will reduce snap-fit's reusability, it may indicate that the temperature used in training and AD processes should be another factor to be optimized in the future research work. Higher temperature may speed up SMP's shape changing process in order to reduce the disassembly time, but it may also hurt the cross links in the SMPs. Once the cross links in the SMPs are destroyed, the shape changing process will also be delayed. The heating temperature should be decided according to SMP transition temperature and reusability requirements of specific product or component. After optimizing all the design parameters, integrating the new snap-fit into product design will be explored with an aim to simplify manufacturing and assembly processes and reduce

Figure 6 Stress caused by training process



Note: (a) Release angle = 188°, (b) release angle = 248°, and (c) release angle = 308°

the cost. Finally, a lifecycle cost analysis of the new snap-fit design should be conducted to justify the feasibility of applying the new design into industrial products since the current price of SMP is relatively higher than traditional plastic materials. A trade-off point should be identified since the new snap-fit may not reduce the product lifecycle cost if the reduced disassembly cost cannot cover the extra material cost.

References

Bonenberger, P.R. (2005), *The First Snap-fit Handbook: Creating and Managing Attachments for Plastic Parts*, 2nd ed., Hanser-Gardner Publications Inc, Cincinnati, OH.

Boothroyd, G. and Alting, L. (1992), "Design for assembly and disassembly", *CIRP Annals-Manufacturing Technology*, Vol. 41 No. 2, pp. 625-36.

Carrell, J., Tate, D. and Zhang, H.C. (2010), "Robust analysis of the active disassembly process", *Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology*, pp. 1-6.

Carrell, J., Tate, D., Wang, S. and Zhang, H.C. (2011), "Shape memory polymer snap-fits for active disassembly", *Journal of Cleaner Production*, Vol. 19, pp. 2066-74.

Chiodo, J.D. and Boks, C. (1999), "A feasibility study on active disassembly using smart materials – a comparison with conventional end-of-life strategies", *Proceedings of CIRP 6th International Seminar of Life Cycle Engineering, Kingston, Canada*, pp. 92-101.

Chiodo, J.D. and Boks, C. (2002), "Assessment of end-of-life strategies with active disassembly using smart materials", *The Journal of Sustainable Product Design*, Vol. 2 Nos 1/2, pp. 69-82.

Chiodo, J.D., Billett, E. and Harrison, D. (1998a), "Active disassembly", *The Journal of Sustainable Product Design*, No. 7, pp. 26-36.

Chiodo, J.D., Billett, E. and Harrison, D. (1998b), "Investigations of generic self disassembly using shape memory alloys", *Proceedings of the IEEE International Symposium on Electronics and the Environment*, pp. 82-7.

Chiodo, J.D., Billett, E. and Harrison, D. (1999), "Active disassembly using shape memory polymers for the mobile industry", *Proceedings of the IEEE International Symposium on Electronics and the Environment*, pp. 151-6.

Chiodo, J.D., McLaren, J., Billett, E.H. and Harrison, D.J. (2000), "Isolating LCDs at end-of-life using active disassembly technology: a feasibility study", *Proceedings of the IEEE International Symposium on Electronics and the Environment, San Francisco, CA, USA*, pp. 318-23.

Cho, J.W., Kim, J.W., Jung, Y.C. and Goo, N.S. (2005), "Electroactive shape-memory polyurethane composites incorporating carbon nanotubes", *Macromol. Rapid Commun.*, Vol. 26, pp. 412-16.

Duflou, J.R., Willems, B. and Dewulf, W. (2006), "Towards self-disassembling products design solutions for economically feasible large-scale disassembly", *Innovation in Life Cycle Engineering and Sustainable Development, Part 2*, Springer, New York, NY, pp. 87-110.

Huang, W.M., Yang, B., An, L., Li, C. and Chan, Y.S. (2005), "Water-driven programmable polyurethane shape memory polymer: demonstration and mechanism", *Appl. Phys. Lett.*, Vol. 86 No. 11, pp. 114105-1-114105-3.

Ji, F., Zhu, Y., Hu, J., Liu, Y., Yeung, L. and Ye, G. (2006), "Smart polymer fibers with shape memory effect", *Smart Mater. Struct.*, Vol. 15, pp. 1547-54.

Lendlein, A. and Langer, R. (2002), "Biodegradable, elastic shape-memory polymers for potential biomedical applications", *Science*, Vol. 296 No. 5573, pp. 1673-6.

Lendlein, A., Jiang, H.Y., Junger, O. and Langer, R. (2005), "Light-induced shape-memory polymers", *Nature*, Vol. 434, pp. 879-82.
Leng, J.S., Lan, X., Liu, Y.J. and Du, S.Y. (2011), "Shape-memory polymers and their composites: stimulus methods and applications", *Progress in Materials Science*, Vol. 56 No. 7, pp. 1077-135.
Mohr, R., Kratz, K., Weigel, T., Lucka-Gabor, M., Moneke, M. and Lendlein, A. (2006), "A initiation of shape-memory effect by inductive heating of magnetic nanoparticles in thermoplastic polymers", *PNAS*, Vol. 103, pp. 3540-5.
Sodhi, M. and Knight, W.A. (1998), "Product design for disassembly and bulk recycling", *CIRP Annals – Manufacturing Technology*, Vol. 47 No. 1, pp. 115-18.
Spillman, W.B. Jr, Sirkis, J.S. and Gardiner, P.T. (1996), "Smart materials and structures: what are they?", *Smart Mater and Structs*, Vol. 5 No. 3, pp. 247-54.

Corresponding author

Hua Li can be contacted at: hua.li@tamuk.edu

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