Influence of grain refiner addition and heat treatment on the mechanical properties of Al-Si alloy

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Abstract: *In the present investigation, an attempt is made to study the effect of addition of grain refinement on Al-Si alloy, when it is subjected to the combined grain refiner addition (Al-5T-1B) and subjected to mechanical vibration and heat treatment. The material is tested for hardness property and dry sliding wear properties. The results of the present investigation indicate that there is a considerable improvement in the hardness valves, microstructure and resistance for wear.*

Keywords: *Aluminium-silicon alloys, Grain refinement, Heat treatment, Microstructure, Vibration*.

I. Introduction

Al-Si casting alloys play an important role in the field of cast aluminum alloys. They have been widely used in automobile, aerospace and engineering industries due to their excellent castability, weld ability, high corrosion resistance, thermal conductivity, ductility property, good mach inability etc. Many investigators (1) have reported the mechanism of grain refinement, and the development and usage of grain refiners (2). By refining the grain structure, improvement in some of the properties of castings is highlighted (3). Grain refinement involves the suppression of columnar and twinned columnar grains to produce equiaxed grain structure (4). The T6 heat treatment is associated with the decrease of secondary dendrite arm spacing, spheroidization of fine eutectic silicon and precipitation hardening. (5)The various techniques developed to achieve grain refinement of aluminum alloys are:

- Mechanical agitation of the molten alloy
- Rapid cooling
- Addition of grain refiners or master alloys to the melt
- Heat treatment

II. Experimental Details

2.1 Details of alloy

The alloy selected for the study is Al-Si alloy. The composition of the alloy was determined by subjecting the alloy to chemical test by optical emission spectrometer and the results of same is shown in table below.

Elements	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti	Al
%By Wt	0.04	0.41	6.82	0.34	Max0.03	0.02	Max0.07	Max0.01	Max0.03	0.08	Rem

Table 1: Composition of Al-Si alloy

2.2 Details of grain refiner

The refiner selected for the study was Al-5%Ti-1B.
Quantity of Al-Si alloy melted = 3.92kg
Percentage grain refiner addition = 2%
Weight of grain refiner to be added = (4000*0.02) = 80gms

2.3 Details of the permanent mould

Permanent mould made of EN 19 steel coated with mould coat and preheated to 300^{0}C was used in the present investigation. The details of the mould used is shown in figure-1

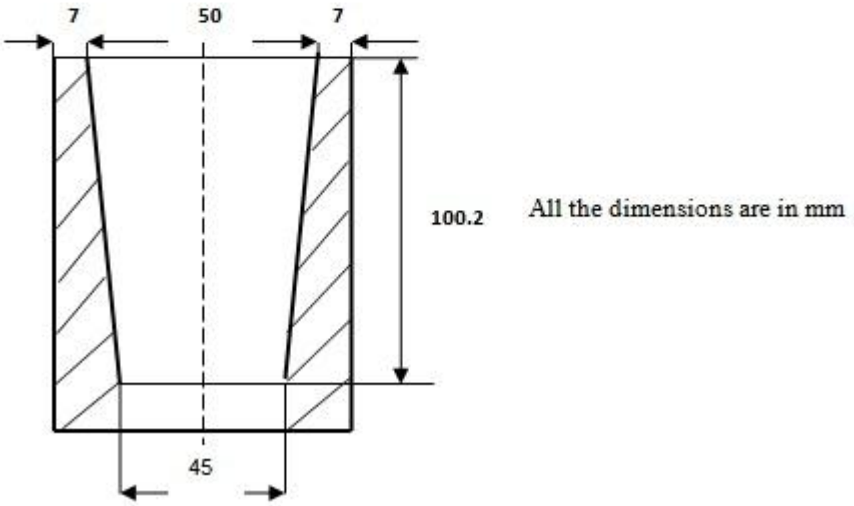

Fig.1 Details of the mould

2.4 Vibration set up

The detail of the vibration set up used in the present investigation to generate vibrations is illustrated in the block diagram.

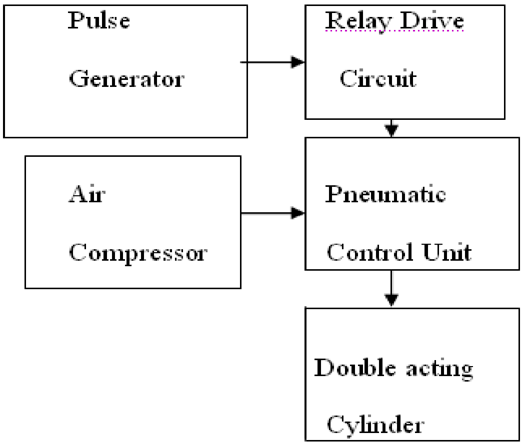

Fig: 2 Pneumatic vibration apparatus (Block diagram)

2.5 Specification of the set up

1. Switching mode power supply adapter: I/P: 100-240V,O/P: 12V, 1A The function of the above adapter is to convert A.C supply of 240V to D.C supply of 12 V.

2. Square Wave Pulse Generator: Figure: 3 show the photograph of the square wave pulse generator. This is used to supply current. The tests can be carried out by varying frequencies and amplitudes. Frequency Range: 1Hz to 1MHz, Amplitude: 0-5 V

Fig: 3 Square wave Pulse Generator

The tests were conducted by increasing (varying) the frequency levels and keeping amplitude constant. This will affect the rate of the movement of the piston in the cylinder. i.e it increases the rate of piston movement in turn results in the increase of vibration rate of the die (into which treated molten alloy is transferred).

3. **Relay Drive Circuit**: This essentially consists of a switching type NPN transistor (2N-3035)

Fig4: Relay Drive Circuit

This relay drive circuit is used to switch on and off the power supply to the solenoid controlled pneumatic control valve.

4. Pneumatic control unit: A single solenoid pilot operated valve with spring return mechanism was used. This unit operates in the pressure range 2-10 bar.

Figure5: Pneumatic control unit

The air flow can be controlled using solenoid controlled valves. Solenoid controlled valve is shown in Figure5a. The top of the valve body of the pneumatic control unit has two ports that is connected to a double acting pneumatic cylinder. The bottom of the valve body has a single pressure line (connected to air compressor) in the center with two exhausts at its sides. The solenoid is mounted on one side. When actuated (when the relay drive circuit switches to ON condition) it will drive the central spool towards the solenoid coil. In this position the air flows through the center port P to port A. Port A being connected to the bottom of the pneumatic cylinder results in making the die to move up. Presently air retained in the other side of piston is made to flow out of the cylinder through the port B and port R2.

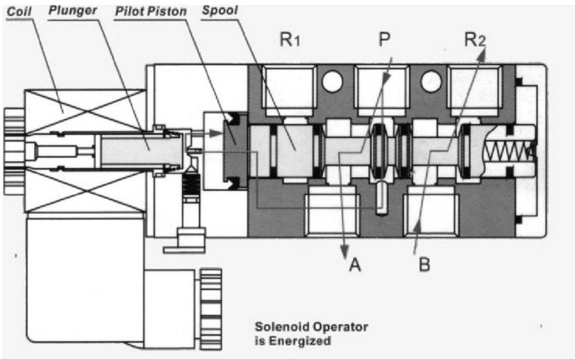

Figure 5a: Single solenoid control valve

When deactivated (when the relay drive circuit switches to OFF condition) there will be no current flow to the solenoid coil hence due to the spring action central spool will move away from the solenoid coil as shown in the figure 5b. Due to this, air flows through the center port P to port B. Port B being connected to the top of the pneumatic cylinder results in making the die to move down. Air retained in the other side of piston is made to flow out of the cylinder through the port A and port R1.

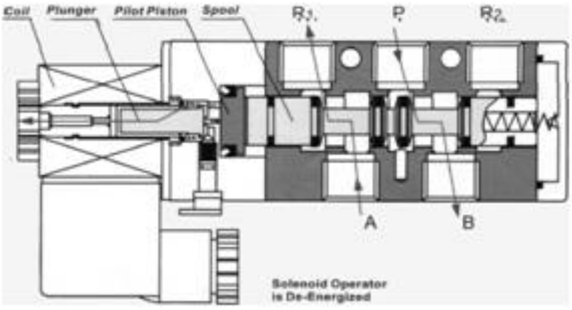

Figure 5b: Single solenoid control valve

Double Acting Pneumatic Cylinder
Details of the double acting pneumatic cylinder is shown in figure: 6
Maximum Stroke Length of the piston being 120mm.
Diameter of the piston: 30mm
Diameter of the piston rod: 12mm

Figure 6: Double Acting Pneumatic Cylinder

Experiments were conducted by varying the frequency of power supply and varying the rate of vibrations (keeping its amplitude constant.

2.6 Melting and treatment of the alloy

Melting was carried out in an electrical resistance furnace graphite crucible coated with mould coat dried and preheated was placed in the furnace. Ingot was transferred into the crucible. The furnace was started to melt the alloy. When the metal attained the molten condition (temperature was 750C) degassing was carried out using hexachloroethane degassing tablets. The dross was skimmed off and the clean molten metal was transferred into the mould. Following treatment of the molten alloy were carried out in different stages:

- Without addition of refiner and without mechanical vibration.
- By inducing the mechanical vibration to the molten metal without addition of refiner.
- By addition of refiner and by inducing of mechanical vibration to the molten metal.

The duration of inducing the mechanical vibration into the molten metal was maintained for 180 seconds till the alloy solidified. The intensity of the vibration was varied by increasing the frequency of vibration 4 to 10Hz by keeping amplitude of vibration to 3mm. After solidification and cooling to the room temperature the cast samples were ejected out from the mould. The cast samples were machined as per the required dimensions to carry out different tests and all the samples were subjected to a T6 heat treatment.

2.7 T6 Heat treatment

The heat treatment allows dissolving Mg2Si, homogenizing the solid solution and spherodise the eutectic silicon. The solution treatment was carried out at 540C for 6h followed by quenching immediately in the hot water and then artificial aging at 170 C for duration of 5h, followed by air cooling.

2.8 Microstructure examination

The of Microstructure examination forms important part of the investigation This helps in characterization of composition structure and properties of the material. Steps involving in the preparation of specimen for microstructure examination are: Sectioning, Grinding, Polishing, Etching.

2.9 Hardness measurements

Hardness measurements were carried out using a Brinell hardness tester. An average of three hardness measurements across the section was considered for the analysis.

III. Wear Test

The wear test were carried out using the pin on disk type wear testing machine.

Procedure employed:

- The surface of the disc was cleaned with acetone to remove dust, dirt present on the surface.
- The specimen was initially weighed and it was fixed in the holder provided and locked by tightening the screw.
- Motor was switched on and speed was adjusted to the required valve.
- Apply the weight on the hanger.
- The test was conducted for 5, 10,15mins duration of time. At the end of each time motor was switched off; specimen removed from the holder was cleaned and weighed precisely in the electronic balance.
- Weight loss was considered for wear analysis(i.e. the difference between the initial and final weight)

Formulae used for finding weight loss and wear rate is as shown below
Weight loss (W_L) = Initial weight – Final weight = $W_1 – W_2$ grams

- Rubbing Velocity (V) = $(2\pi rN)/60,000$
  r = Track radius in mm
  N = RPM of disc
- Wear rate = Weight loss/Distance traveled = $W_L / 2\pi rN$ gm/m.

Test parameters:

- Disc diameter: 380mm
- Diameter of specimen (d) : 6mm
- Length of the specimen : 28mm
- Speeds studied: 400 rpm, 800 rpm, 1200 rpm
- Track radius : 40mm
- Load applied: 20N
- Duration of tests: 5min, 10min, 15min.

IV. Results and Discussion

The results of the investigation carried out on the grain refinement of Al-Si alloy subjected to mechanical vibration with and without the addition of refiner and T6 heat treatment discussed under the following headings.

- Hardness test
- Microstructure examination
- Dry sliding wear test.

4.1 Hardness test

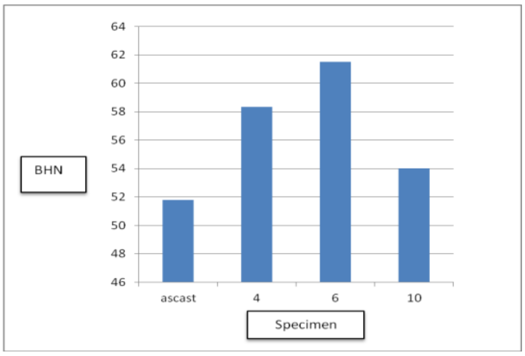

Fig7: shows the variation of hardness valves for different condition

It is observed that the frequency of vibration affects the value of hardness of the alloy. It is seen that the maximum hardness value (61.5BHN) is noticed for the alloy subjected to 6Hz frequency. Ascast specimen exhibits least hardness value (51.8 BHN).The study indicate that vibration has an influence on the hardness values of the specimen.

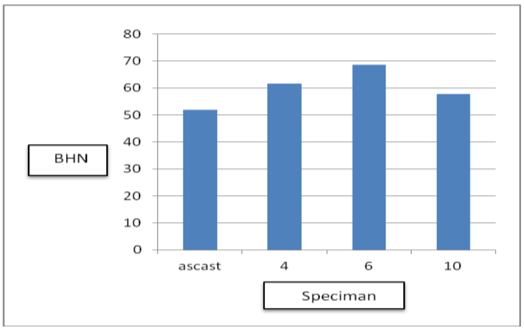

Fig8 : shows the variation of hardness valves with different conditions (with grain refiner addition and heat treatment)

It seen that maximum value of BHN is observed in the 6Hz specimen subjected to the combined effect of frequency for vibration and with grain refiner addition. An increase of 32.6% in hardness is seen with the specimen subjected to combined grain refiner addition and vibration as comparison with ascast condition.

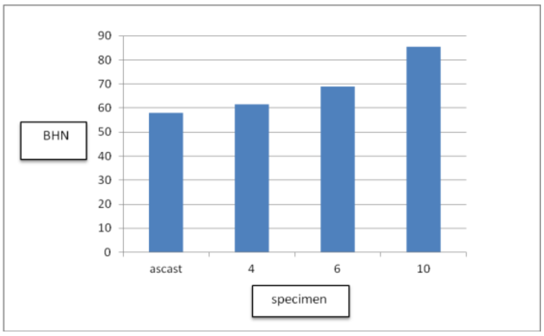

Fig9 **:** Effect of combined effect of grain refiner and vibration and T6 Heat treatment with 5h artificial aging

The figure 9 indicates that maximum value of BHN is observed in 10Hz specimen subjected to the combined effect of frequency for vibration and with grain refiner addition along with T6 heat treatment for the period of 5h of artificial aging. An increase of 47.7% is seen with the specimen subjected to combined grain refiner addition and vibration and heat treatment as comparison with ascast condition.

4.2 Microstructure examination

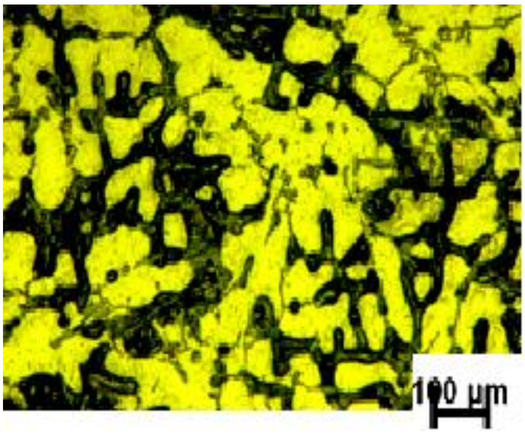

Fig10: Ascast Al-Si alloy

Figure-10 shows the structure of the ascast Al-Si alloy (without refiner addition and without the inducing vibration) It is observed that the structure of alloy is comprised of coarse aluminum matrix, which is strengthened by Si precipitates, and a dispersion of eutectic silicon particles and intermetallics. The secondary dendrites arm spacing (SDAS) was found to be 68.03μm calculated by linear intercept method.

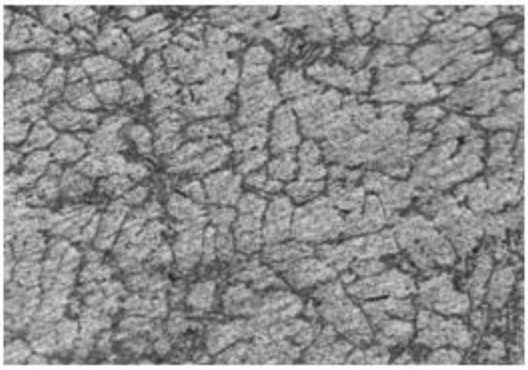

Fig11: 4Hz vibration without grain refiner

Fig12: 6Hz vibration without grain refiners

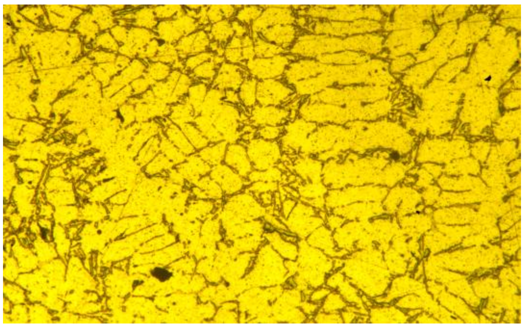

Fig13: 10Hz vibration without grain refiner

Fig11, 12 and 13 shows the photo micrograph of the specimen subjected to vibration frequency of 6 and 10Hz respectively. It can be seen that, the grain size is reduced and close grain structure is observed compared to the ascast structure. (SDAS of 4Hz, 6Hz and 10Hz are found was 39.3, 36.92 and 53.8µm respectively)

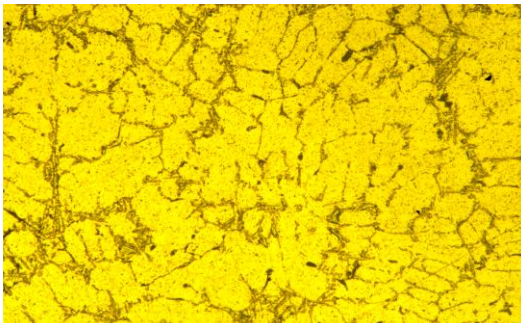

Fig14: 6Hz vibration with 2% grain refiner

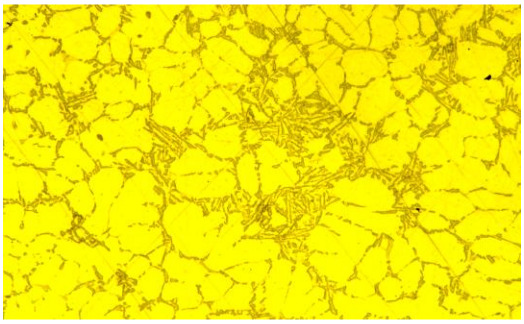

Fig15: 10 Hz vibration with 2% grain refiner

Figure14&15 shows the photo micrograph of the specimen subjected to an addition of 2% grain refiner and vibration frequency of 6 and 10Hz. It can be seen that, the grain size is reduced and close grain structure is observed. The SDAS of 6 and 10Hz was found to be 36.92 and 53.8µm respectively.

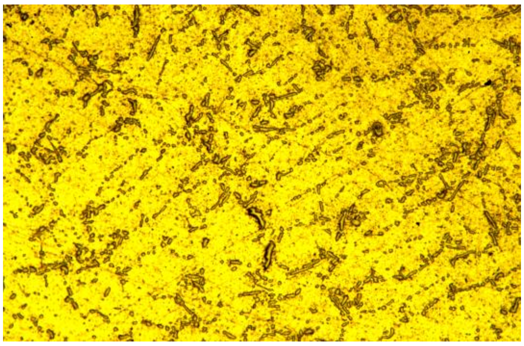

Fig16: 4 Hz vibration with 2% GR with T6 HT

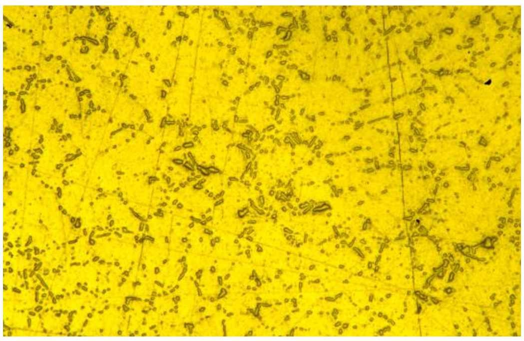

Fig17: 6Hz vibration with 2% GR with T6HT

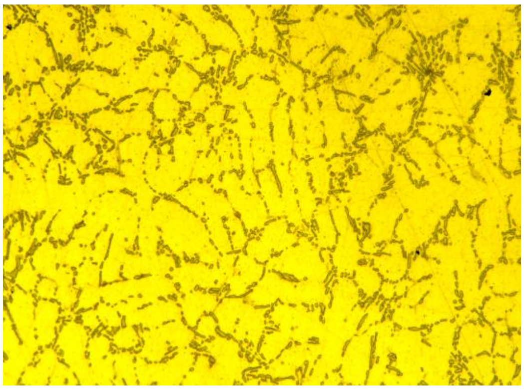

Fig18: 10Hz vibration with 2% GR withT6 HT

Figure16, 17&18 shows the photo micrograph of the specimen subjected to an addition of 2% grain refiner and vibration frequency of 4, 6 and 10Hz withT6 heat treatment and 5h of artificial ageing. It can be seen that, the 10Hz vibration with 2% grain refiner with T6 heat treatment gives higher BHN because of equeaxied grains. (The SDAS of 4, 6 and 10Hz are found to be 41.4, 39.5, 35.6μm respectively)

4.3 Dry sliding wear test.

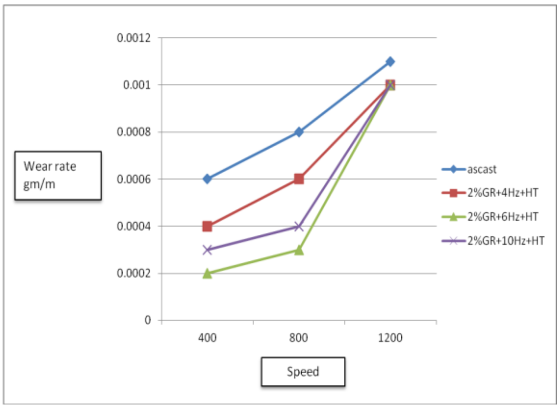

Fig19: wear rate versus speed

It can be seen from the figure19 that with increase in speed, the wear rate also increases. The maximum wear rate is seen in the as-cast specimen. There was a 10% improvement in the resistance for wear upon the alloy subjected to mechanical vibration with addition of grain refiner and T6 heat treatment and 5hours of artificial ageing.

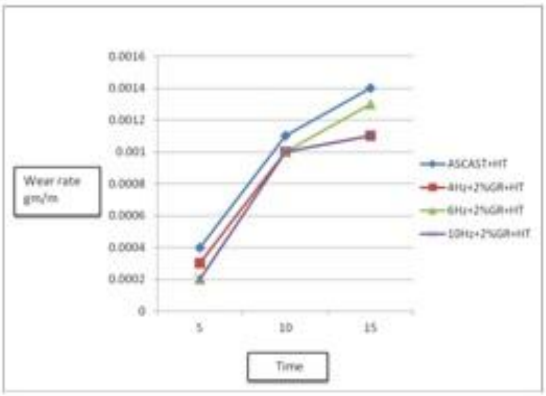

Fig20: wear rate versus time (1200rpm).

It can be seen from the figure that with increase in time, the wear rate also increases. The maximum wear rate is seen in the as-cast specimen. There was a 21.4 % improvement in the resistance for wear upon the alloy subjected to mechanical vibration with addition of grain refiner and T6 heat treatment.

V. Conclusions

From the investigation carried out on Al-Si alloy castings subjected to combination of vibration and grain refiner with T6 heat treatment, the following observations can be made.

5.1 Microstructure examination

Coarse acicular silicon particles are seen distributed along primary aluminum dendrite boundaries. Grain structure gets reduced and a closed structure is observed when the alloy is subjected to combination of vibration and grain refiner addition with T6 Heat treatment.

5.2 Mechanical properties

Hardness values get improved upon subjecting the castings to grain refinement and vibration with T6 Heat treatment (5h of artificial aging). The maximum hardness value of 85.54 BHN is observed in the specimen when it is subjected to combination grain refiner with vibration and T6 heat treatment. (An increase of 47.7% in hardness values is observed). This indicates that vibration has an influence on the mechanical properties of the Al-Si alloy castings.

5.3 Wear behavior

There was a considerable improvement in the resistance for wear upon the alloy subjected to mechanical vibration with addition of grain refiner and T6 heat treatment. There was a 21.4 % improvement in the resistance for wear upon the alloy subjected to mechanical vibration with addition of grain refiner and T6 heat treatment.

VI. Acknowledgement

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