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LIFETIME ANALYSIS OF HDPE FLOATING WATER WHEEL AS AN EFFECT OF THERMAL DEGRADATION

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ABSTRACT

The water wheel is an important tool used in cultivating vaname shrimp, which functions as depositing oxygen in cultivation ponds. HDPE is a polymer material used as a waterwheel float. In outdoor working environment of the waterwheel float in the cultivation pond, which exposed to direct sunlight, resulting in an increase in temperature. The influence of heat from the sun certainly affects to the degradation process of the waterwheel float. In this study, HDPE material was given a variety of heat treatments. The variation of heat given was adjusted to the results of observing field conditions for 1 week where the water wheel was used in the aquaculture pond. The variations of heat treatment given were without treatment, lowest, average, highest temperature heat treatment, and cycles. This research aims to determine the effect of heat on reducing tensile strength, the condition of the functional groups contained, and the service life of the material. The result was a 9% reduction in tensile strength in the samples that were given the highest thermal treatment. Degradation due to thermal effects is proven by the decrease in wave peak intensity for each functional group contained in the HDPE material. Calculation of the estimated service life of the HDPE float must be replaced as fast within 5 months.

Keywords: *service life, tensile strength, polymer, float, maintenance*.

ABSTRAK

Kincir air merupakan alat yang penting yang digunakan dalam melakukan budidaya udang vaname, yang berfungsi sebagai alat deposit oksigen pada kolam budidaya. HDPE adalah salah satu material polimer yang digunakan sebagai pelampung kincir air. Lingkungan kerja pelampung kincir air pada kolam budidaya yang terletak di luar ruangan, yang tentunya terpapar matahari langsung, mengakibatkan adanya peningkatan temperatur. Pengaruh panas dari matahari tentunya berpengaruh pada proses degradasi pelampung kincir air. Dalam penelitian ini, material HDPE diberikan variasi perlakuan panas. Variasi panas yang diberikan disesuaikan hasil observasi kondisi lapangan selama 1 minggu di tempat kincir air digunakan pada kolam budidaya. Variasi perlakuan panas yang diberikan yaitu tanpa perlakuan, perlakuan panas temperatur terendah, rata-rata, tertinggi, dan siklus. Penelitian ini memiliki tujuan untuk dapat mengetahui pengaruh panas terhadap penurunan kekuatan tarik, kondisi gugus fungsi yang terkandung, serta umur pakai material. Didapatkan hasil penurunan 9% kekuatan tarik pada sampel yang diberi perlakuan termal tertinggi. Degradasi akibat pengaruh thermal dibuktikan dengan turunnya intensitas puncak gelombang pada tiap-tiap gugus fungsi yang terkandung di dalam material HDPE. Perhitungan perkiraan umur pakai pelampung HDPE paling cepat harus diganti dalam jangka waktu 5 bulan.

Kata kunci: umur pakai, kekuatan tarik, polimer, pelampung, perawatan.

INTRODUCTION

Vaname shrimp (Litopenaeus vannamei) has various superior characteristics, making it one of the most widely cultivated types of shrimp in Indonesia. This is because vaname shrimp can produce significant shrimp production (Suwoyo & Tampangallo, 2015). Shrimp is one of the main commodities in Indonesia whose production must be increased. Because this type of shrimp is easy to cultivate, many shrimp pond farmers in Indonesia are developing vannamei shrimp cultivation. In addition, this vaname shrimp has a fairly high level of life preservation and stocking density. To increase shrimp production, the construction and development of shrimp ponds must be carried out consistently by adhering to productive principles, based on sustainable and long-term environmental technology. However, to develop intensive vaname shrimp cultivation, tools or facilities are needed that can facilitate the process. One of the tools that can be used by shrimp pond farmers to help cultivate vannamei shrimp is a waterwheel. This water wheel can make the fertilization process easier, mix the properties of pond water in the upper and lower layers, and stabilize water quality. Waterwheels on shrimp ponds can simplify the process cleaning the pool by moving the garbage in the water the farm goes to the disposal. The waterwheel rotation system can make the water wavy so that the water waves produced by the waterwheel rotation can cause garbage to be eliminated (Widodo *et al*., n.d. dalam Evalina *et al*., 2022). Waterwheels are also very important to supply oxygen to pond waters so that the shrimp do not lack oxygen. Thus, the waterwheel ensures that the farmed shrimps get sufficient amount of oxygen. Waterwheels in intensive ponds can also be used as current engineers. This is to collect sludge and waste from feed residues to the central drain, evaporate toxic gases, and stirring to distribute plankton vertically in the morning (Wafi *et al*., 2013). In addition, the waterwheel can also be used as a means to convert water energy into mechanical energy in the form of rotation on the shaft contained in the mill (Tuapetel & Poerwoko, 2018). The waterwheel in this vaname shrimp pond has several components as its constituents, namely there are driving motors, gear boxes or gears, buoys, mill leaves, pillow blocks, iron engine pangkon, and axle rods (Nugraha *et al*., 2017).

The float (floating boat) is very important for the water wheel because it functions as a floating medium. With a float, the water wheel can be placed and used properly in pond waters. The material used for buoys must be lightweight and corrosion resistant, one of which is HDPE. However, if the water wheel is used for a long period of time and is continuously exposed to sunlight, it can cause the float to degrade. Degradation occurs when a molecule undergoes chemical changes to gradually break down into simpler molecules or compounds. The mechanical properties of a material will decrease due to degradation, one of which is tensile strength. The tensile strength of the material will decrease along with the level of degradation given to the material. One of the degradation that can reduce the mechanical properties of the material in the form of tensile strength is the result of thermal.

It is still not possible to know or predict how long floats made of HDPE material experience degradation during use. So, to be able to determine the estimated service life of the HDPE material as a float, a tensile test is carried out. After conducting tensile testing, it can be known for the large mechanical properties contained in HDPE when after deterioration. It also aims to be able to determine the decrease in mechanical properties that occur in the material. In addition, FTIR testing was carried out to determine the functional groups contained in the material after experiencing thermal degradation. By testing and determining the estimated useful life of HDPE floats, pond farmers can replace the floats before they experience damage that could be detrimental when the water wheel is operating or in use.

MATERIALS AND METHOD

This section will discuss the primary literature review supporting this article, as well as the research methods.

High Density Polyethylene (HDPE)

The material that will be used in this research uses HDPE material as a waterwheel float. HDPE is a linear thermoplastic polymer made from ethylene monomer through a catalytic process. HDPE has the advantage of being stronger and more resistant to higher temperatures. Mostly, HDPE is combined with other fillers which can improve the properties of it. These additives can function as dyes, fillers, antioxidants, UV (ultraviolet) absorbers, anti-stickers, and many more (Muharrami, 2013).

HDPE is made in a strong, ductile and rigid condition. HDPE has a rough degree of bonding between its molecular components which is very strong and has strong tensile bonds as well. HDPE is polyethylene which has a high density with a density of 0.941 – 0.965 g/cm^3 (Tjipto *et al*., 1995). Some of the advantages possessed by HDPE are resistant to corrosion, easy to form, easy to recycle, and durable because it has strong durability. This HDPE material will be formed into several specimens which will be tested later.

Thermal Degradation Test Equipment

In thermal degradation testing, a equipment is needed in the form of an oven that can provide heat or thermal treatment to HDPE specimens before testing. The oven used is the LabTech brand with ISO 9001 and the KIRIN oven. In the oven, the HDPE specimen will be given thermal treatment at a certain predetermined temperature.

Apart from using an oven, a thermometer is also used to be able to control the temperature given to the specimen so that it remains constant and maintained. Apart from that, the thermometer is also useful for finding a suitable temperature and is suitable for adjusting the temperature given to the specimen according to a predetermined temperature.

Tensile Strength Test Equipment

The equipment used to determine the tensile strength of the main material is a tensile testing machine. This machine is used to perform tensile testing on specimens after being subjected to thermal treatment. The machine used has MPa units with a capacity of 100 kN.

Apart from using a tensile testing machine, a vernier caliper is also an important tool used to measure specimen dimensions before and after tensile testing. For the material used in tensile testing, 15 specimens with different thermal treatments have been given.

FTIR Test Equipment

The equipment used to determine which main chains are broken in the polymer after being exposed to thermal treatment is the FTIR test equipment. This tool will produce results in the form of a graph showing what functional groups or main chains will be reduced. Samples used for testing are from control specimens or without thermal treatment and specimens with the lowest tensile strength results (highest thermal treatment).

Research Method

In previous research, Nazriati, et al. 2019. States that solar radiation and ultraviolet radiation can cause degradation of styrofoam plastic. The mechanism of degradation of the mechanical properties of polymers is proven by the occurrence of oxidation which produces styrene oxide from styrene monomer. The degradation will be more massive in direct proportion to the length of exposure time. Research shows a decrease in the quantitative value of tensile strength, along with an increase in the relative concentration of styrene oxide, and causes a change in the appearance color of the styrofoam to yellow and cracks appear to occur.

Degradation of HDPE polymer can be minimized by adding filler according to research by Muharrami, et al., 2013. Adding filler to HDPE can improve the mechanical properties of HDPE film 13% of the sample without adding filler, but on thermal degradation resistance, adding filler to HDPE has no significant effect. The material's resistance to thermal degradation is at a point of 100°C before experiencing physical changes.

In Pratama, J. A., 2023, the tensile strength value possessed by HDPE with a temperature of 170 °C is 514.489 MPa and the tensile strength value possessed by a temperature of 210 °C is 383.349 MPa. So it can be concluded that in the study, the lower the thermal treatment given, the higher the tensile strength of HDPE material. But on the contrary, the higher the temperature, the lower the tensile strength possessed by the HDPE material.

In this research, a field study was carried out to obtain temperature data that will be used to provide thermal treatment to the material. The field study was carried out by observing for 1 week at the location where the waterwheel was operating. The temperature data that has been obtained will be calculated as an average and varied into several thermal treatments. The variations in thermal treatment are the lowest thermal treatment with a temperature of 29℃, the average thermal treatment is 34℃, the highest thermal treatment is 40℃, and the thermal cycle treatment is 34℃, 40℃, 37℃, and 29℃. The tools and materials that must be prepared to be able to carry out this research are 15 specimens of HDPE material, oven, vernier caliper, thermometer, tensile testing machine, and FTIR test equipment.

Experiments are carried out by providing thermal treatment or exposure to materials that have been in the form of specimens according to predetermined standards. The thermal test was carried out using an oven with several variations of thermal treatment within 15 days. Thermal treatment at constant load (low, average, and peak thermal treatment) is given exposure for 24 hours in a row. Meanwhile, thermal treatment under fluctuating loads (cycle thermal treatment) is given exposure every 4 hours in stages.

After the specimen is given thermal exposure, a tensile test is carried out on the HDPE specimen. Specimens with each variation of thermal treatment were subjected to replicate tensile tests 3 times. This aims to validate the tensile strength value produced during testing. Specimens to be subjected to tensile testing must comply with predetermined standards. The standard used for tensile testing of polymer materials is ASTM D638-14 Type IV.

To be able to analyze the functional groups contained in the material, it is necessary to carry out FTIR testing. The samples used for testing were from control specimens or without thermal treatment and specimens with the lowest tensile strength results (peak thermal treatment). The resulting data is in the form of graphs and several functional groups that experience changes in the form of decreases, terminations, or additions.

The data results from several tests that have been carried out will be processed and calculated to determine the estimated useful life of the HDPE material. The resulting tensile test data can be determined through the following calculations:

$$\sigma_u = \frac{Load\ (P)}{Area\ (A)} \quad (1)$$

Where Load (P) is obtained from the results of tensile tests that have been carried out by each specimen. Area (A) which is the cross-sectional area of the specimen being tested. With this formula, the maximum tensile strength of each specimen with different thermal treatment can be known.

Meanwhile, on the results of the FTIR test data, an analysis of changes in the functional groups contained in the material is carried out through graphs of test results. To be able to determine the estimated useful life of a material, tensile strength data is needed with the following calculations:

$$x = \frac{y}{z} \quad (2)$$

Where x is the estimated useful life, y is the result of calculating exposure days with a determined percent reduction until the remaining tensile strength of the material remains usable, z is the decrease in mechanical properties obtained from data on the tensile strength of the material.

RESULT AND DISCUSSION

From several tests that have been carried out, results are obtained which are then processed into several analyses.

Analysis of Tensile Strength in Various Thermal Treatments

From the tests and data that have been taken and calculated using equation (1), the tensile strength results for HDPE are obtained as follows:

Table 1. Thermal Variation Tensile Strength

Ultimate Tensile Strength (UTS)					
Temp. / Mat.	Normal	Low	Average	Peak	Cycle
HDPE	26.92 ±1.60	26.90 ±2.67	26.60 ±0.97	24.60 ±2.92	24.84 ±0.23

From the data obtained in Table 1, it can be said that the tensile strength value of untreated HDPE material has a maximum value used as a control specimen of 26.92 MPa. Meanwhile, the specimen with the minimum or lowest tensile strength value had the highest thermal treatment of 24.60 MPa. This is in accordance with research by Suyadi, 2010, which stated that the research results in the form of tensile strength of non-recycled HDPE had an average value of 21.72 N/mm^2.

a. Relationship of Tensile Strength with Thermal Constant Load

The relationship between tensile strength and constant load is the relationship between the tensile strength of the material with the low, average, peak thermal treatment variations, and the material without treatment. The thermal exposure is given constantly within a predetermined exposure period. The relationship is contained in the graph as follows:

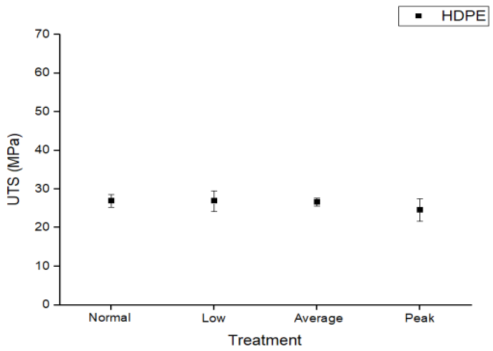

Figure 1. Relationship of Tensile Strength with Constant Load

In the graph in Figure 1. it can be said that variations in thermal treatment with constant load provide a decrease in the mechanical properties of HDPE material with specimens without treatment being the control for other variations in thermal treatment. The specimens with the lowest exposure experienced a decrease in mechanical properties by 1%, the specimens with average exposure experienced a decrease in mechanical properties by 2%, and the specimens with the peak exposure experienced a decrease in mechanical properties by 9%. The greatest decrease in mechanical properties is owned by the specimen with the peak thermal exposure with the lowest tensile strength value from other thermal exposures. While the maximum tensile strength value is the greatest for control specimens that do not get thermal treatment.

b. Relationship of Tensile Strength to Fluctuating Loads

The relationship between tensile strength and fluctuating load is the relationship between the tensile strength of a material with variations in cyclic thermal treatment compared with variations in average thermal treatment and without treatment. The relationship is contained in the graph as follows:

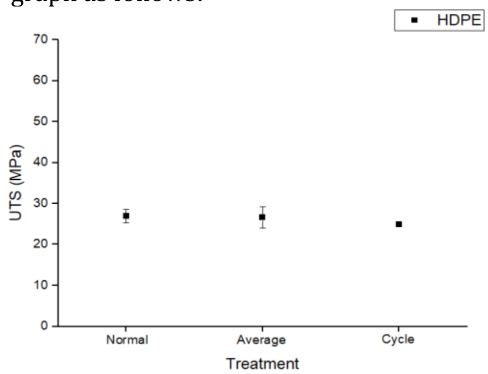

Figure 2. Relationship of Tensile Strength of Fluctuating Loads

In the graph in Figure 2, it can be said that variations in thermal treatment with fluctuating loads result in a decrease in the mechanical properties of the HDPE material. Specimens without treatment become control or reference specimens for other thermal treatment variations. In varying thermal treatment cycles, the mechanical properties decreased by 8%. The decrease in cyclic exposure is greater than the decrease in mechanical properties experienced by average thermal exposure. This proves that the fluctuating load given to a material can have a greater influence on the mechanical properties of the material than the constant load received by a material.

FTIR Analysis

FTIR analysis was carried out with the aim of knowing the functional groups contained in the material before and after thermal exposure. The following is a graph of the results of FTIR test data, namely:

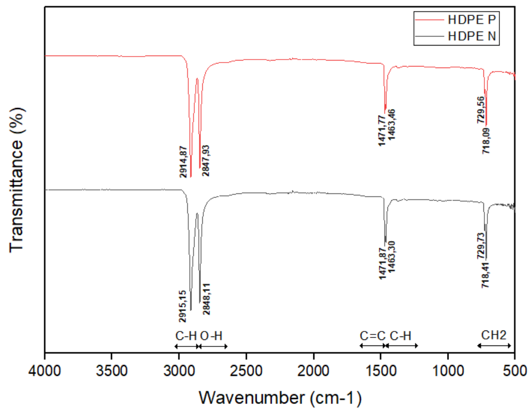

Figure 3. HDPE FTIR Chart

Figure 3. shows a graphic comparison of the results of FTIR analysis on HDPE material without treatment (HDPE N) and HDPE material with the peak thermal treatment (HDPE P). In this graph, material without treatment is shown with a black line, while material with the highest thermal treatment is shown with a red line.

In HDPE N with a wave peak of 2915.15 cm^{-1} and HDPE P with a wave peak of 2914.87 cm^{-1}, it shows the C-H stretch (Alkyl) functional group. In HDPE N with a wave peak of 2848.11 cm^{-1} and HDPE P with a wave peak of 2847.93 cm^{-1} shows the functional group –OH stretch (Carboxylic Acids). The appearance of –OH bonds can be caused by other materials containing these bonds in a material. The wave peak of 1471.87 cm^{-1} belongs to HDPE N and 1471.77 cm^{-1} belongs to HDPE P indicating the chemical bond C=C stretch (Aromatic Compounds). The wave peak of 1463.30 cm^{-1} belonging to HDPE N and 1463.46 cm^{-1} belonging to HDPE P shows the C-H bend (Alkyl) chemical bond. Meanwhile $–CH_2$ bend (Methylene) is shown by the peak wave of HDPE N, namely 718.41 cm^{-1} and HDPE P, namely 718.09 cm^{-1}.

From the functional group analysis of FTIR results that had been carried out on HDPE without treatment and HDPE with the peak thermal treatment, it was found that there was no addition or removal of functional groups. However, in this material there is a decrease in the wave peak intensity in each functional group contained in the material.

Estimated Service Life of the Material

Estimating the useful life of a material can be useful for knowing the length of use of the material so that vannamei shrimp pond farmers can replace it before major damage occurs to the float. The float receives static loads in the form of motors, wheels, shafts, frames and receives dynamic loads in the form of pump vibrations.

The load to be calculated on the windmill float is a static load. Calculation of the static load will determine the actual force received by the buoy. So that the total static load received is 440 N with a float area of 1650 x 290 mm. The calculation of the actual force from the static load received by the buoy is as follows:

$$F = \frac{440}{478{,}500} \quad (3)$$

So the actual force received by the float is 0.001 N/mm^2. From the actual force obtained, the tensile strength value of the material from various variations of thermal exposure can still accept the actual force of the static load on the float. The decrease that occurred was 90% until the remaining tensile strength was 10%. The determination of the useful life calculation comes from the percentage value of reduction in mechanical properties of tensile strength which has been calculated for each variation of thermal treatment. The percentage decrease occurred over 15 days. Thus, the remaining HDPE tensile strength value of 10% is obtained in the following table:

Table 2. Tensile Strength 10%

UTS 10% (MPa)				
Temp. Mat.	Low	Average	Peak	Cycle
HDPE	2.69	2.66	2.46	2.48

From the remaining 10% tensile strength of the material before it was damaged, it can be calculated the estimated service life of a material using equation (2). Data on the estimated useful life of a material that has been calculated is in the following table:

Table 3. Estimated Lifetime of HDPE

Temp. / Mat.	Lifetime (months)			
	Low	Average	Peak	Cycle
HDPE	44	22	5	6

In Table 3. it can be said that the specimen with the low thermal treatment has a longer estimated service life compared to other variations of thermal treatment. While the shortest estimated service life is owned by the specimen with the peak thermal treatment. This is because the specimen is subjected to thermal exposure with a constant maximum temperature for a long period of time so that the mechanical properties of the material decrease. There is a graph of the relationship between tensile strength and estimated service life which is known as follows:

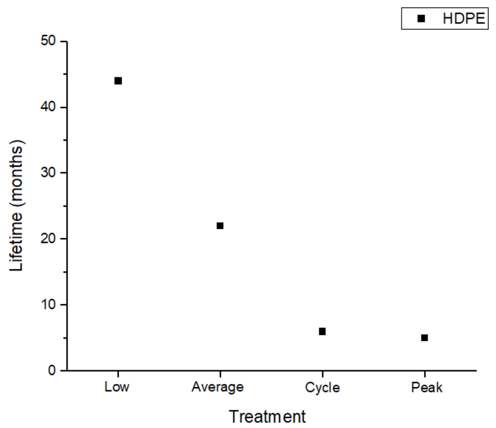

Figure 4. Tensile Strength Relationship with Lifetime

In the graph shown in Figure 4. it can be said that the tensile strength of a material has a relationship and influences the service life of the material. The smaller the value of the tensile strength of a material, the shorter or faster the service life it has. In this graph, the decrease in mechanical properties with service life of each variation of thermal treatment does not experience a sharp decrease. The service life that experienced the fastest decrease in mechanical properties was owned by the specimen with the highest thermal treatment with a time of 5 months until the tensile strength decreased and the remaining 10% before experiencing damage.

CONCLUSION

Based on the experiments and data analysis that has been carried out, it can be concluded that found 9% reduction in tensile strength in the samples that were given the highest thermal treatment. Degradation due to thermal effects is proven by the decrease in wave peak intensity for each functional group contained in the HDPE material. Calculation of the estimated service life of the HDPE float must be replaced as fast within 5 months.

REFERENCE

ASTM (American Society for Testing and Material). 2015. ***Standard Test Method for Tensile Properties of Plastics,*** **ASTM International.** United States.

Evalina, N., Pasaribu, I. F., Syahputra, A. M., Indrayani, Rahayu, T. (2022). *Pemanfaatan Kincir Air untuk Tambak Udang di Desa Pematang Guntung.* **SEMNASTEK**. pp. 97-99.

Fitri, A. A. (2022). Studi Pengujian Gugus Fungsi (FTIR) Biopolimer dari Kulit Singkong untuk Meningkatkan Viskositas Air Formasi sebagai Bahan Alternatif dalam Mengatasi *Water Coning*. **Tugas Akhir**. Teknik Perminyakan, Universitas Islam Riau, Pekanbaru.

Muharrami, K. L. (2013). *Uji Karakterisasi Tarik dan Termal Plastik HDPE dengan Filler Abu Layang dan Silane.* **Jurnal Rekayasa**. Vol.6, No.2, pp. 82-88.

Mulyono, B. A. & Purwanto, H. E. (2021). *Umur Simpan (Shelf Life) dan Umur Pakai (Service Life) Selang Termoplastik Elastomer (TPE) dari Perspektif Standarisasi, Produsen, dan Konsumen.* **Seminar Nasional Teknik Industri Universitas Gadjah Mada**. pp. 13-17.

Nazriati, Fajaroh, F., Santosa, A. & Rizqiyah, L. (2019). *Efek Radiasi Sinar Matahari dan Sinar Ultra Violet pada Plastik Styrofoam Kemasan Makanan dan Minuman.* **Jurnal Cis-Trans**. Vol.3, No.1, pp. 23-33.

Ni'mah, L. Y., Atmaja, L. & Juwono, H. (2009). *Sintesis dan Karakterisasi Film Plastik HDPE Pengemas Herbisida Menggunakan Filler Abu Layang Kelas F.* **Jurnal**. Vol.9, No.3, pp. 348-354.

Nugraha, A. P. N., Agus, M. dan Mardiana, Y. T. (2017). *Rekayasa Kincir Air pada Tambak LDPE Udang Vannamei (Litopenaeus vannamei) di Tambak Unikal Slamaran*. **Jurnal PENA Akuatika**, Vol.16, No.1, pp. 103-115.

Plota, A. & Masek, A. (2020). *Lifetime Prediction Methods for Degradable Polymeric Materials – A Short Review*. **Materials**, pp. 1-25.

Pratama, J. A. (2023). Analisis Pengaruh Temperatur Terhadap Kekuatan Tarik dan Tekuk Pada Proses Hot Pressing Komposit Hybrid Serat

Bambu dan Serat Daun Nanas Bermatriks HDPE. **Tugas Akir**. Teknik Mesin, Institut Teknologi Sumatera.

Putri, S. A. (2022). Analisis Pengaruh Variasi Parameter 3D *Printing* terhadap Kekuatan Tarik, Kekuatan Impak, dan *Building Time* Menggunakan Metode Taguchi-*Grey Relational Analysis*. **Tugas Akhir**. Teknik Desain dan Manufaktur, Jurusan Teknik Permesinan Kapal, Politeknik Perkapalan Negeri Surabaya.

Suwoyo, S.H. & Tampangallo, R.B. (2015). *Perkembangan Populasi Bakteri pada Media Budidaya Udang Vaname (Litopenaeus vannamei) dengan Penambahan Sumber Karbon Berbeda.* **Jurnal.** Vol.4, No.1, pp. 365-374.

Suyadi, (2010). *Kaji Eksperimen Perbedaan Kekuatan Tarik Sampel Berbahan Plastik HDPE dengan LDPE Daur Ulang.* **Jurnal.** pp. 14-18.

Tjipto, S., B. Edy, S., Tunjung, I. Y., Suparjono, M., Bambang, S., Prayitno, Agus, H. I., Budiono, S., Tumpal, P., Futichah, Wagiyo, H. W. (1995). *Pengaruh Rasiasi Neutron Cepat terhadap Sifat Fisik dan Mekanik Polimer HDPE, LDPE dan PS.* **Prosiding Pertemuan dan Presentasi Ilmiah**. pp. 104-109.

Tuapetel, V. J. & Poerwoko, D. (2018). *Perancangan Kincir Terapung pada Sungai untuk Pembangkit Listrik*. **Seminar Nasional Pakar ke 1**, pp. 39-45.

Wafi, A., Ariadi, H., Mahmudi, M. & Fadjar, M. (2020). *Tingkat Transfer Oksigen Kincir Air Selama Periode Blind Feeding Budidaya Intensif Udang Putih (Litopenaeus vannamei)*. **Journal of Fisheries and Marine Research**, Vol.4, No.1, pp. 7-15.