Number 1 Volume 24 January 2018 Journal of Engineering

The effect of Laser Shock Peening on Fatigue Life Using Pure Water and Hydrofluoric Acid As a Confining Layer of Al – Alloy 7075-T6

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ABSTRACT

Laser shock peening (LSP) is deemed as a deep-rooted technology for stimulating compressive residual stresses below the surface of metallic elements. As a result, fatigue lifespan is improved, and the substance properties become further resistant to wear and corrosion. The LSP provides more unfailing surface treatment and a potential decrease in microstructural damage. Laser shock peening is a well-organized method measured up to the mechanical shoot peening. This kind of surface handling can be fulfilled via an intense laser pulse focused on a substantial surface in extremely shorter intervals. In this work, Hydrofluoric Acid (HF) and pure water as a coating layer were utilized as a new technique to improve the properties and to harden the treated surface of the Al - alloy 7075-T6. Fatigue life by means of laser peened workpieces was improved to 154.3%, 9.78%, respectively, for Hydrofluoric (HF) and pure water compared to un-peened specimens. And the outcomes of Vickers hardness test for laser shock peening with acid and pure water as well as un-peened specimens were 165.2HV30, 143.95HV30 and 134.7HV30, respectively showed a significant improvement in the hardness property.

Keywords: laser shock peening, aluminum alloy 7075-T6, pure water, HF acid, fatigue life.

تأثير السفع بالليزر على عمر الكلال باستخدام ماء نقي وحامض الهيدروفلوريك كطبقة حاجزة لسبيكة الالمنيوم T6- 7075

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الخلاصة

تعتبر عملية السفع بالليزرعملية تكنولوجية كفوءة نتيجتها نشوء اجهاد انضغاطي متبقي اسفل السطوح المعدنية ولذلك هذه العملية مهمة لتحسين عمرالكلال وخصائص المواد مثل مقاومة البلي والتآكل وهي ذات موثوقية عالية وتقلل من تدهور البناء الجزيئي. وهذا النوع من التعامل الميكانيكي بدون اتصال مباشر مع سطح المعدن. وتجري هذه العملية من خلال تسليط نبضات مكثفة من الليزر على سطوح المعادن وبأوقات قليلة جدا. وفي هذا البحث أستخدم حامض الهيدروفلوريك كتقنية جديدة وماء نقي كطبقة فوق سطح السبيكة الالمنيوم 7075 لتحسين خواص السبيكة وتصليد سطح السبيكة. وقد تحسن عمر الكلال باستخدام الليزر الى 154.3% ، 9.78% على التوالي عند استعمال حامض الهيدروفلوريك والماء النقي مقارنة مع السطوح غير المعالجة. والنتائج المستحصلة من فحص فيكرز للصلادة عند استخدام حامض الهيدروفلوريك والماء النقي والقطع غير المعالجة كانت كالتالي (165.2HV30، 143.95HV30، 134.7 HV30) على التوالي وأظهرت تحسن مهم في خاصية الصلادة.

1. INTRODUCTION

The utilization of laser-generated power pulses to enhance the fatigue lifespan through stimulating compressive residual stress close to the surfaces of material components has been in expansion for further than 30 years **Clauer**, **et al., 1983.** Laser shock peening (LSP) is a cold working method, capable to initiate compressive residual stress and thus augment the resistance of the element to process fatigue. The important results obtained from this method were improved in hardness, tensile strength and fatigue life, which is attributed to LSP. The enhance in fatigue life is a result of significant residual surface stresses formed due to shock process, and to expand under the metal surface **Hu,** and **Yao, 2006**. Research by **Gomez, et al., 2005,** concluded that the Al- alloy 6061-T6 by using low energy Nd: YAG laser with a coating, laser peening can expansively obtain better surface compressive stress and micro-hardness with a little enhance in surface roughness. This compressive stress leads to an increase in fatigue life and wear resistance of the metal. This process permits, peening of complex geometries (e.g., aero-engine blades, fastener holes, etc.). It was experimentally found out that the LSP usually generates compressive areas, more than 4 mm deep, in comparison to about 0.25 mm generated by the conventional shoot peening, **Ding**, and **Ye**, **2006**.

Some corporation, **Mannava**, **et al**., **1996 – Casarcia**, **et al., 1996,** used either small output energy (around 1 J/pulse) or elevated energies (20 - 40 J/pulse) lasers on aluminum alloys. **Sano**, **et al., 2000 – Azer**, **et al.**, **2004**. They have revealed the practicability of using LSP in an industrial situation, with a big range of design (flanked by 5 mm and 10 mm diameters of impacts), materials and applications. The advantages of the treatments against other impact treatments (ultrasonic peening, shoot-peening, deep rolling) are quite well known; a good protection of surface roughness, and big affected depths (superior to 3 mm).

Surface treatment by LSP for the most parts includes applying an ablative or thin aluminum tape to the surface of a segment. This tape is vaporized by a laser beat, delivering a quickly extending plasma. The plasma is bounded by stagnant water sprayed on the surface. And the impact is to create a high-amplitude, short interval shock wave in the workpiece, **Achintha**, and **Nowell**, **2011**. As the stress wave engenders, more restricted plastic distortion happens and, once the shock has been applied, nonconformity between the plastically deformed material and encompassing elastic locally creates a residual stress, **Achintha**, and **Nowell**, **2013**. **Privy**, **2000,** illustrated the application of laser shock peening to lessen fatigue, to make improvement in hardness of the surface of the materials and to enhance the microstructural characteristics of metallic materials. Such upgrades were assumed to expand their benefit life for particular appliances. Additional research by **Prevey**, and **Jayaraman**, **2005**, demonstrated that powerful laser accomplishes better surface completely, style, minimize the organization time and additionally initiate profound shock waves into the material surface. This operates the laser shock peening an unrivaled method and more valuable towards a mechanical function. **Qureshi, et al., 2001**, likewise gave a case of the aviation producing area where the laser shock peening is gradually surpassing the other traditional technique of surface treatment utilizing shoot peening. **Hackel, 2005**, publicized that a beat of 25 J used for 25 ns was created by Nd: Yttrium Lithium Fluoride (YLF) laser.

The shocks were concentrated onto the specimen, and the region to be peened was sheltered with a material (black shaded glue tape) that is actives as an ablative in addition to thermal securing coating. Water was set up to stagnate over the specimens to absorb the laser pulse vitality and thermal shock. Ionization and vaporization amid water supported peening are commonly produced because of the photon penetration in the liquid, which creates a plasma in the supported liquid. A get-together of plasma inside the water creates stunning waves that instantly enter into the treated surface of the specimen, adjacent plastically compressing the surface. The plastic strain after that fortifies compressive residual stress in the specimen at an around the depth of 1- 8 mm, relying upon the laser pulses factors and other technical considerations. In this work, it was determined, to analyze the state where an ablative layer exists as hydrofluoric acid (HF) as a new technique and pure water as a coating layer and to describe the fatigue lifespan associated with different levels of stress levels. The aim of this research is to evaluate the impact of HF acid and pure water, as a covering surface layer of the laser on the fatigue properties utilizing Al-alloy 7075.

2. EXPERIMENTAL WORK

The substance of the test is an aluminum alloy of 7075-T6, which is normally utilized for airplane structural auxiliary parts and other exceedingly focused on basic applications where high quality and enormous improvement to corrosion are required. The profile and measurements of the workpiece according to (DIN 50133) standard assurance are shown up in **Fig.1**.

The examinations were performed at the SIER-Baghdad (State Company for Inspection and Engineering Rehabilitation). Table (1) and (2), this examination gave the chemical compositions and static properties of Al- alloy 7075-T6.

The fundamental objective of the investigation tests is to produce the S-N curve for all cases that mentioned in the test arrange. A reverse cyclic bending loading test was performed by utilizing AVERY fatigue testing, mechanical machinery at various rates of cycles, as shown in **Fig.2**. The applied load is computed from the bending moment and the deflection angle applied to specimens. A revolution mechanical counter is associated specifically with the engine to record the number of cycles.

2.1 Laser Peening Process

There are diverse manners to build the absorption of the power of the laser, which is a high-energy laser pulse beat on the surface, and the black tape on the surface of the workpiece is a precise approach to improve this power with water as a repression layer.

The procedure essentially focuses the laser pulses alone to present an intensity of plasticity or plastic deformation, which empowers the surface of the material to pick up quality through stimulation of compressive residual stress. The procedure is complex as it includes water-assisted, laser preparing and the utilization of an absorptive layer, which both give an additional impact. First, a coating of black absorptive tape is set on the substrate to be dealt with, which is made from polyvinyl chloride (PVC) as the backing materials coated with rubber adhesive which could resist high voltage, high temperature and high ability of absorption of energy of the laser. The absorptive coatings in whichever case assist the material's size to absorb the occurrence laser pulses.

Second, the stagnant or stream of pure water is prepared to pour above the treated surface of the material to be peened. Third, the exceptional beat of the laser is guided at the material to be peened.

These pulses of laser act similar to a shoot (bead) like in the mechanical shoot peening. In this work, hydrofluoric acid (HF) was utilized as another technique to upgrade the force of the laser that affects on the Al- alloy 7075-T6.

The treated surface of this layer is vaporized, keeping on to absorb energy, creating a plasma. The extension of the plasma is guarded by the water, resulting in an extremely rapid augment in pressure, which generates a shock wave within the material, plastically distorting closest to surface section. And to evade the reaction between the acid and the alloy, an exceptionally slight 100 µm layer of nylon covers the surface of the workpiece, then pouring the HF acid with 1-2 mm in depth over the workpiece, precisely on the contracted zone of the workpiece, as shown in **Fig. 3**, which demonstrates the workpiece with black tape and slight covering of acid. Prior to the laser treatment, the workpiece surface was smoothened with 200 emery paper to give Ra (average roughness) about 0.6 µm.

There are evident points of interest that empower the laser shock peening to subsist a much predominant method, in contrast with the other mechanical shoot peening methods. They are given as follows:

- Infiltration profundity of compressive remaining residual stress within the treated material is recognized to be much more prominent than that prompted by the shot peening surface treatment. This implies that the failure rate of treated surface with LSP is much lesser than that of the treated surface by means of the mechanical shoot peening method.
- Laser shock peening additionally makes available enhancements in surface roughness dissimilar to the mechanical shoot peening method that produces rough generated surface.
- Mechanical shoot peening needs instrument alters, though no device alter is necessitated for laser shock peening. This wipes out the needless set-up of working time and thus raises the fabrication throughput.
- No recollection of the impacted shoot is necessitated as the laser shock peening is a contact-less process with abnormal state of stability and repeatability permitting the surface treatment with negligible support and high-quality standards.
- All laser construction currently operate with better movement system and flexibility of progress that guides the programming of complex profile and geometries, that permits a simple programming from a two-dimensional (2D) to three-dimensional (3D) PC supported outline (CAD) design (tool way or beam way) and this characteristically permits development in six axes of movement, which is just an offer by the new and costly shoot peening arrangement with six-pivot mechanical movement systems.
- Furthermore, laser shock peening additionally offers an exact quality control where the consideration of the laser is capable of being observed continuously, upon which fault can be promptly repaired.

2.2 Laser Peening Treatment Device

To create a hardened surface lying on metals, Nd: YAG laser has been used. A laser appliance was used in this study (Q-switched neodymium YAG laser) as shown in **Fig. 4**, for laser peening which includes the following properties: Laser wavelength is about 1.065 µm, Pulse duration was 7 nanoseconds, Pulse energy was 300 mJ, and the laser spot is typically 5 mm in diameter.

2.3 Vickers Hardness Test

The Vickers hardness test approach includes of indenting the treated material by a diamond indenter, as a correct pyramid with a quadrangle bottom with an edge of 136 degrees between opposite confronts applied to a load of 30 kgf. The applied load is usually connected for 10 to 15 seconds. The dual diagonals of the breach left in the treated surface succeeding to the expulsion of the load are determined using a microscope and their normal computed. The region of the inclining surface of the space is determined. The Vickers hardness is the remainder obtained by separating the kgf load. And the results come from the Vickers hardness test type LAYREE as shown in **Fig. 5** for laser shock peening, with acid and water in addition to un-peened specimens, was 165.2HV30, 143.95HV30 and 134.6HV30, respectively.

3. RESULTS AND DISCUSSION

After finishing all experimental tests for laser shock peening, AVERY fatigue testing, and the Vickers hardness test, the following issues can be remarked.

3.1 Compressive Residual Stresses Induction

During laser shock peening the treated surface is turned out to be greatly harder and wear safe in the state of substances with existing plasticity. The surface compressive residual stress represses the early failure and prolongs the fatigue life and wear. This is a particular material to parts under frictional and shear stresses. The useful existence of the designing parts is anticipated by either. Fracture mechanics techniques or by measurable fatigue test information determined by stress life (S/N) or strain life (e/N) technique.

3.2 S-N Schemes

Fatigue life against the average recognized nominal stress range data used for the treated specimens and un-peened specimens are plotted to determine S-N curves which are appeared in **Fig.6**.These curves comprise of five levels of stress with three recordings for each level. The test results demonstrate that every point of interest treated at high cycle fatigue region by LSP with HF acid and pure water accomplished significant improvement in life and strength arrive at 154.3%, 9.78% respectively compared to un-peened specimens. Three S-N curves for three cases were drawn in S-N curves for the shock laser with pure water, HF acid, and un-peend alloy can be formulated by the equations, $\sigma f = 863.18 * N f^{-0.157}$, $\sigma_f = 890 * N_f^{-0.162}$ and $\sigma f = 870 * N_f^{-0.159}$, respectively.

Increment in load capacity and bending strength amid bending as appeared in **Fig.7**, tension exists in the lower sector of the structure and compression happens on the high sector.

The forces performing on the minor surface are tense, the connotation that the structure in bending has the probable to fracture if the tensile stress reaches the ultimate tensile strength of the structure. The higher segment of the structure is in compression. This compression over the structure area makes a state of balance at the middle plane. Laser shock peening could incite extra compressive stress on the minor layer where the tensile stress is affecting. This would turn around the positive tensile stress into negative compressive stress and hinder the structure from cracking.
It would likewise improve the resistance of materials to break (crack start and grow from surface imperfections) thus upgrading and enhancing bending load capability. While the peened treated surface is in compression, necessitated force to instigate yielding at the base surface (layer) will likewise increase. Because of the utilization of surface treatment handle, for example, shot peening or laser shock peening, the stimulated compressive stress performing on the minor surface will imply that the performing created for the duration of the bending moment have to beat the peening-initiated compression. This demonstrates the bending strength of the material is upgraded by commencing a surface layer of compressive stress, permitting the treated material to include under higher bending strengths in association with the untreated material under similar bending situations.
The fundamental rule behind laser peening with the test in pure water and HF acid confinement can be clarified as follows. Pure water and HF acid are not utilized to cool the surface rather than serving the key capacity of keeping the plasma produced due to the high amount electrons content, compared to pure water which is ineffective enough to pass on all energy of the laser.The laser pulses interact with the opaque overlay surface and is utilized as a medium to infiltrate the laser pulses through the HF acid and pure water in view of the capacity of the acid to pass on the laser influence, which comprises of two combined waves, electrical wave, and magnetic waves, so the acid can pass on the waves in an efficient way through it. Hence it is depicted that the HF acid - laser fatigue lives extend the lifetime compared to pure water-laser fatigue lives and un-peened lives. This extension represents the factor of safety in comparison with the base metal behavior.

4. CONCLUSIONS

The high cycle fatigue life increment resulting from HF acid laser as a powerful technique influencing on the cyclic fatigue relies on upon the affected stress. At lower stresses, the fatigue life is more noteworthy than that of un-peened. However, at high stress, the stresses in general in large increments because of the high stress, which is the main factor in controlling the crack growth, i.e. quickens the propagation of the crack and the crack growth rate turns out to be faster than those of lower stresses. It can give a picture of that the compressive residual stress avoids the initiation and propagation of the cracks. And this lead to, that hydrofluoric acid - laser peening is an impact surface treatment technique better than water - laser peening and shows signs of improvement high cycle fatigue properties and hardening the surface of aluminum alloy 7075-T6 as the Vickers hardness test point out this conclusion. This improvement articulates to the consideration of safety measures correlation with the base metal finish.

REFERENCES

- Achintha, M., and Nowell, D., 2011, *Residual Stress in Complex Geometric Features Subjected to Laser Shock Peening*, J Strain Anal Eng, Journal of Materials Processing Technology 211 (6):1091-1101.
- Achintha, M. Nowell, D., Shapiro, K., and Withers, P.J., 2013, *Eigenstrain Modelling of Residual Stress Generated By Arrays of Laser Shock Peeing Shots and Determination of The Complete Stress Field Using Limited Strain Measurements*, Surface Coat Technol,216 pp. 68–77.
- Prevey, P., 2000, *The Effect of Cold Work on The Thermal Stability of Residual Compression in Surface Enhancement In718*. In: Proceedings of the 20th ASM Material Solutions Conference & Exposition, St Louis, MO, 10–12 October.
- Prevey, P. and Jayaraman, N., 2005, *Overview 0f Plastic Burnishing For Mitigation of Fatigue Damage and Mechanism*, In Proceedings of the 9th international conference of Shoot Peening on Fatigue and Fracture of steels, Paris, 6–9 September, pp.267–272.
- Qureshi M., Malik M., and Dubey, R., 2001, *Use of lasers for shoot peening*, In: International Conference on Shoot Peening and Blast Cleaning, p. 171.
- Ding, K., and Ye, L., 2006, *Simulation of Multiple Laser Shock Peening of A 35cd4 Steel Alloy*", J. of Materials Processing Technology, 178, pp. 162-169.
- Mannava, S. McDaniel, A. E., and Cowie, W. D., 1996, *General Electric Company* (Cincinnati, OH), US Patent, 5, 492, 447.
- Casarcia, D. A., Cowie, W. D., and Mannava, S. 1996, *General Electric Company* (Cincinnati, OH). US Patent, 5,584,586.
- Sano, Y., Kimura, M., Sato. K., Obata, M., and Sudo, A., 2000, *Development and Application of Laser Peening System to Prevent Stress Corrosion Cracking of Reactor Core Shroud Proceedings*", of the 8th international conference on nuclear engineering (ICONE-8) (Baltimore, USA).
- Azer. M, and Scheidt, D. 2004, *On The Applications of Lasers and Electro Optics*, Proceedings of Icaleo, 2004 (San Francisco, USA).
- Achintha, M., and Nowell, D., 2011, *Eigenstrain Modelling of Residual Stresses Generated By Laser Shock Peening*, J Mater Process Technol, 211pp.1091–101.
- Clauer, A. H., Walters, C. T., and Ford, S. C., 1983, *The Effects of Laser Shock Processing on The Fatigue Properties of 2024-T3 Aluminum*, Lasers in materials processing. Metals Park (Ohio): ASM International.
- G, Gomez-Rosas., C. Rubio- Gonzalez., and JL. Ocana, 2005, *High Level Compressive Residual Stresses Produced in Aluminum Alloys by Laser Shock Processing*, Applied Surface Science, Vol. 252, pp. 883-887.
- Hackel L, 2005, *Shaping the future-laser peening technology has come of age*, The Shoot Peener, 19 (3): 3.
- Hu, Y., and Yao, Z., Hu, J., 2006, *3D FEM simulation of Laser Shock Processing. In: Surface & Coating Technology* 201, p. 1426-1435.

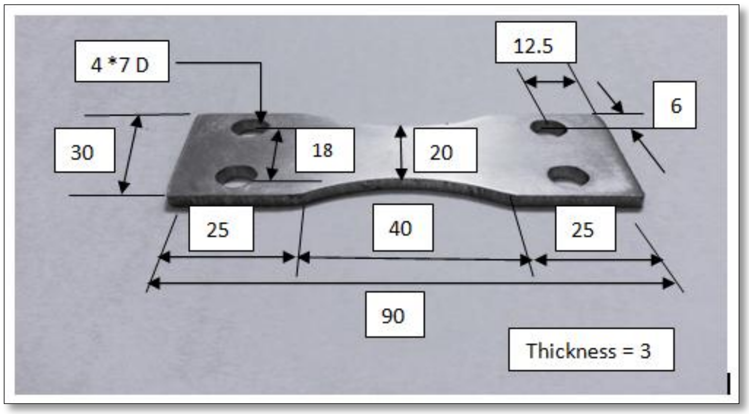

Figure 1. Fatigue specimen geometry, dimensions in millimeter agreement to (DIN 50133) standard requirement.

Table 1. Chemical compositions of the experimental and standard AL- alloy 7075, wt%, [ASTM].

	Zinc	**Titanium**	**Silicon**	**Manganese**
Stand.	6.1 Max.	0.2 Max	0.4 Max.	0.3 Max.
EXP.	5.52	0.028	0.26	0.11
	Iron	Copper	Chromium	Magnesium
Stand.	0.5 Max.	1.2-2	0.28 Max.	2.1-2.9
EXP.	0.24	1.82	0.183	2.15

Table 2. The average mechanical properties of three specimens of Al- alloy 7075-T6.

Property	**Experimental**	**Standard**
Ultimate stress	530 MPa	502MPa
Yield stress	496 MPa	406 MPa
Fatigue strength	206 MPa	156 MPa
Modulus of elasticity	75.6 GPa	74 GPa
Poisson's ratio	0.32	0.33
Elongations %	14.6	16

Figure 2. Fatigue bending machine.

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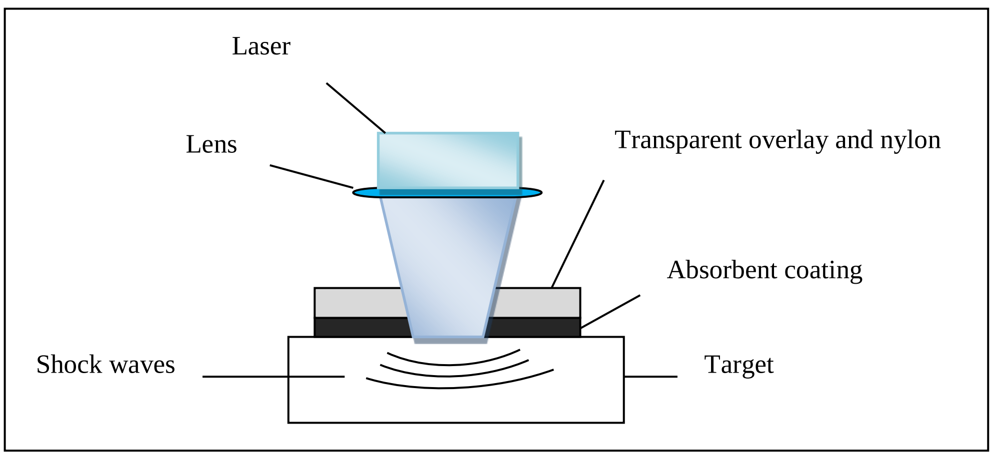

Figure 3. The basic principle of laser shock peening.

Figure 4. Specimen applied under laser power.

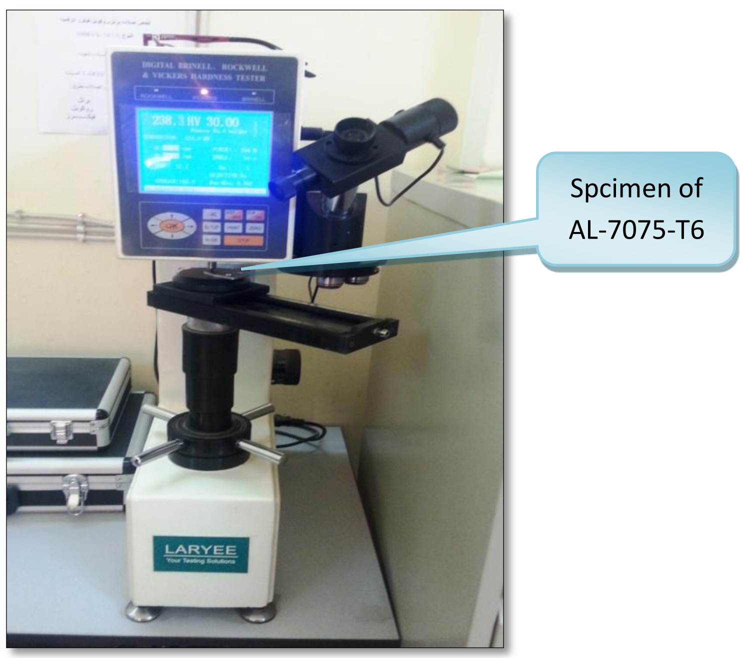

Figure 5. Vickers hardness test.

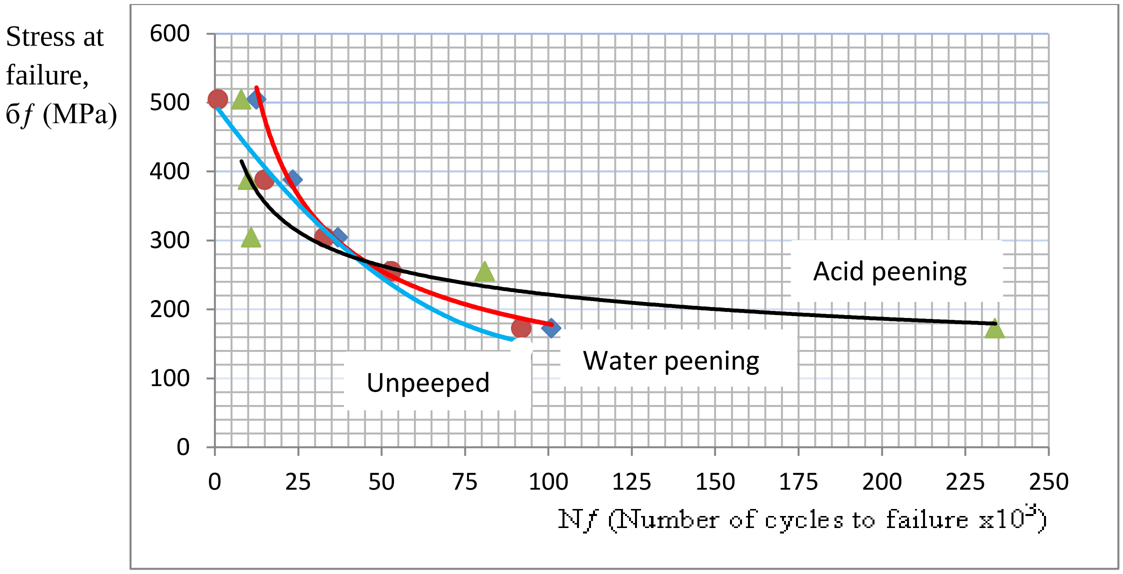

Figure 6. S-N curves at a constant load for un-peened, and laser shock peening with pure water and HF acid.

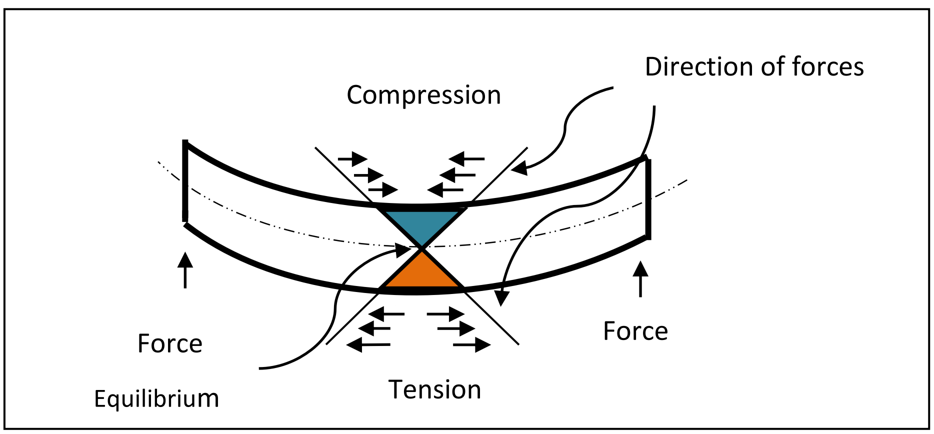

Figure 7. Graphic diagram viewing the allocation of stress across the material in bending.