Investigation of notch fatigue behaviour of Aluminium Alloy-2024 processed through equal channel angular pressing (ECAP)

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Abstract
Grain size is an important key factor in microstructure which affects the mechanical and physical behavior or properties of polycrystalline metals and has a unique role to produce the material with desired mechanical properties. ECAP is a technique, with the help of which grain size can be reduced and desired properties can be achieved. In this research Aluminium Alloy-2024 is investigated. The specimens are prepared and passed via ECAP die, which is intersected at an angle of 100^o degree. Both die and specimens are preheated up to 400^{o}C in an electric furnace. Four point rotating bending test were carried out, S-N were drawn and compared with the as-received material. It was revealed that fatigue life/strength increases considerably in both low and high cycle regimes, with an 18.9% increase in fatigue life of ECAPed processed sample compared to as-received sample, indicating that the ECAP process has significantly improved the fatigue life of Al-2024 aluminium alloy.

Keywords
Equal Channel angular pressing(ECAP), Fatigue Life, Aluminium Alloy-2024

Introduction

Equal channel angular pressing is a severe plastic deformation technique with the help of which strengthening of engineering material took place by introducing shear strain in material which produces refine grain and it leads to the increase in material strength. This technique was developed by Segal in early 1972 [1] and it is considered to be the most effective and dominant technique for severe plastic deformation (SPD). In this process, the sample passes through a die having two channel interesting at an angle ϕ, as a result of which the intense plastic strain imposes on the polycrystalline sample without changing the dimensions of the sample. The changes will occur only in microstructure and grain size [2, 3].

During ECAP method, when material is passes through ECAP die the physical properties of material changes due to the shear straining that has been introduced by severe plastic deformation as a result of which grain refinement took place, which directly affects the mechanical and microstructure of the material[4, 5]. Following are the parameters on which severe plastic deformation depends; Geometry of ECAP die i.e. Die angles, channel shape and size, Hardening behaviour and strength of material, Lubrication, ram speed and temperature during ECAP process. When material is passed through ECAP die shear strain is developed. The ECAP die geometry plays a vital role in developing this shear strain specially Die angle “ϕ” and Corner angle “Ψ” , which is important for grain refinement in material. Die parameter plays a vital role in material refinement and magnitude of effective strain. By decreasing the die angle, higher magnitude of effective strain and higher pressing force on sample is obtained by using ECAP with parallel channel[6, 7].

Engineering materials and structures suffer from fatigue, results in progressive, localized, and permanent deterioration. When repeated strains impinge on a material at nominal stresses much below its static yield stress, this phenomenon happens. Many factors influence the fatigue strength of engineering components, including size and notch presence, material microstructure, manufacturing procedures, and operating environment [8].

In the present study, a commercial 2024 aluminium alloy was selected and subjected to the equal channel angular pressing process. Because of its high strength, this alloy has been widely used in commercial applications such as airplane constructions, particularly under stress wing and fuselage structures. It also employed in high-temperature applications like vehicle engines, cyclic-loading and reciprocating parts like pistons, drive shafts, and brake rotors [9, 10]. A study is needed because of the wide range of cyclic loading applications and the capacity of the ECAP process to improve the mechanical properties of materials [11], so the goal of this study is to explore the fatigue behaviour of the Al-2024 process using ECAP.

Material and method

For this research, Aluminium Alloy-2024 is used. Table 1 shows the mechanical properties of test material [12] and chemical composition of test material has been analysed via EDS before conducting experiment as show in table 2. From the initially purchased rod having diameter of 15mm, the ECAP specimens are machined, having diameter of 10mm and length of 125mm as shown in figure

Table 1-Mechanical properties of Al-2024

Modulus of elasticity E(Gpa)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Poisson's ratio
73.1	469	324	0.33

Table 2-Chemical composition of Al-2024

Element	C	O	Mg	Al	Si	Mn	Fe	Cu	Total
Weight %	19.79	3.33	0.37	71.34	0.48	0.51	0.68	3.50	100
Atomic %	35.75	4.51	0.33	57.37	0.37	0.20	0.26	1.26	

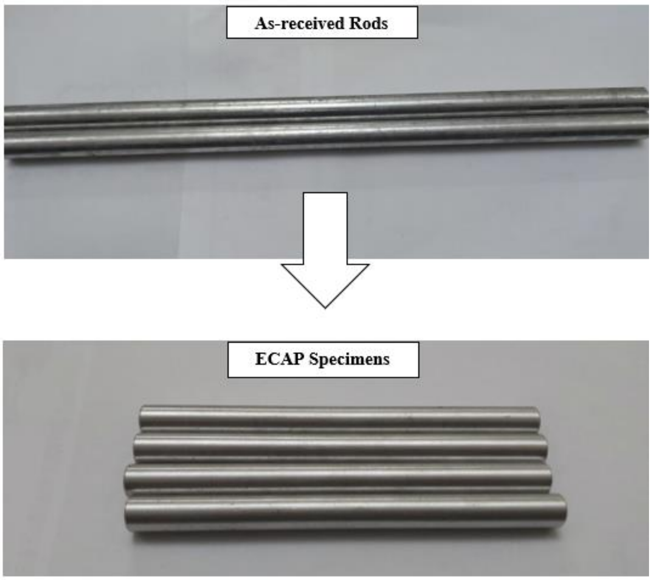

Figure 1. ECAP specimens machined for initially purchased rod

After the preparation of ECAP specimens, pressing technique is applied. For that ECAP die and the plunger was designed and fabricated. ECAP die consist of two halves, joined to form a circular channel having a diameter of 10mm, intersected at an angle of 100^o degree. The die is joined with the help of 6 hexagonal bolts as shown in figure 2 and the material used for manufacturing of die and plunger is ASTM H13 tool steel. This material has high durability as well as excellent wear resistance. Due to good abrasion resistance, good thermal shock resistance heat inspection resistance and high toughness, Tool steel is selected for ECAP die design. The specimens are heated together with the ECAP die up to 400^{o}C for two hours to achieve a uniform temperature overall in order to achieve a smooth flow of the billet via ECAP die. Because the lower critical temperature of Aluminum alloy-2024 is around 400^{o}C, the furnace is intended to maintain a uniform temperature of 400^{o}C which is controlled by an automatic controlled unit. An electrically operated furnace with 4 kW electrical power element is built on the hydraulic press bed for this design consideration as shown in figure 3. High temperature insulation wool (HTIW) isolates the bed and surrounding of the furnace from hydraulic press. The unique purpose of wool is to make it able to withstand more than 1000^o C high temperature.

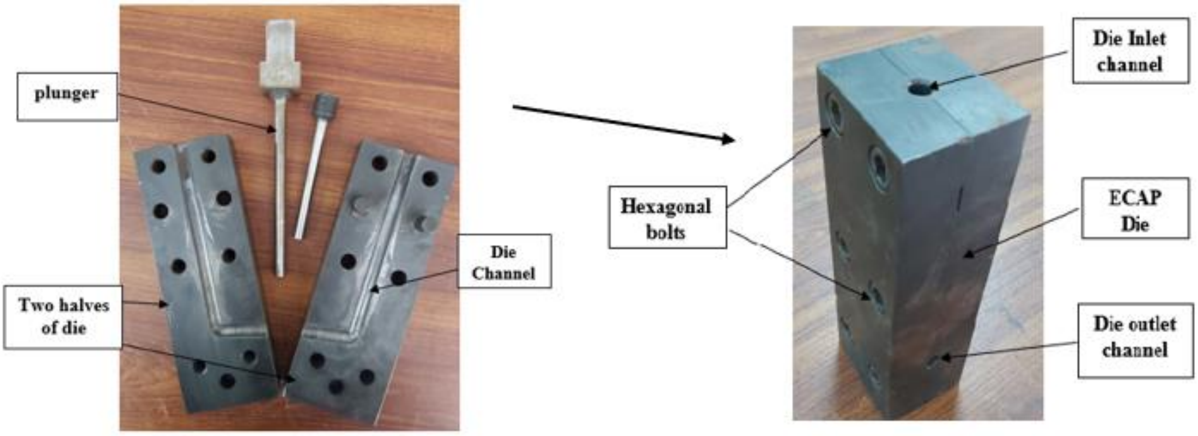

Figure 2. ECAP Die

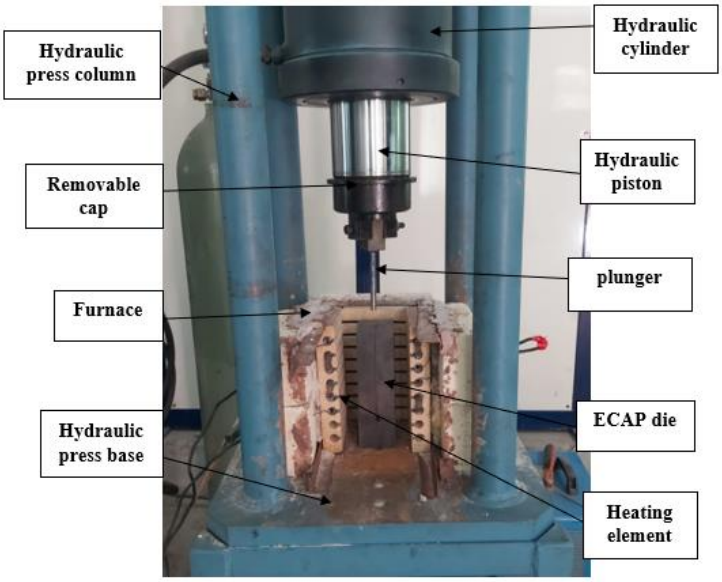

Figure 3. Hydraulic press with furnace

ECAP specimens were passed through the ECAP die. Before pressing lubrication is done on each specimen to overcome the sticky behaviour between die channel and specimens. As the specimens move through the channel, shear deformation takes place at the intersection of a channel. The sample remain in the die till it removed by opening the hexagonal bolts as shown

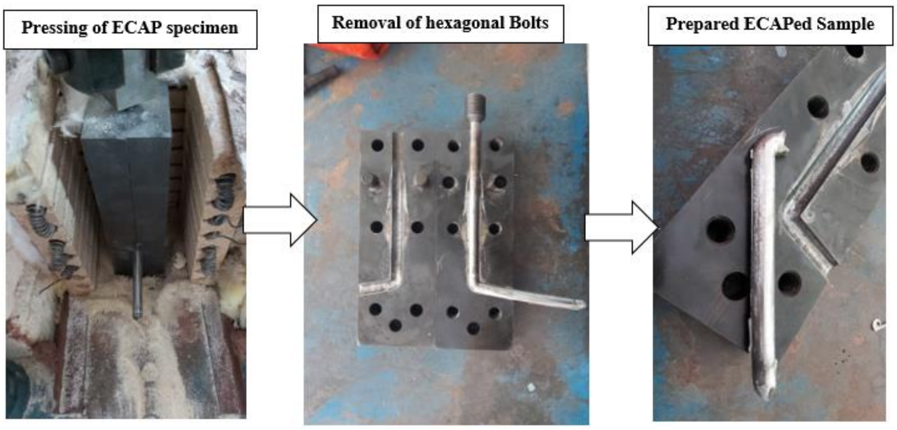

Figure 4. ECAPed sample preparation

in figure 4 and total 18 ECAPed samples were prepared. Then from these ECAPed samples, fatigue samples were prepared for four point rotating bending fatigue test. As shown in figure 5, this machine is used to perform fatigue test on both as received and ECAP sample. This machine is designed and made by standard GB4337-84 “method for rotary bending fatigue tests of metallic materials” and Standard ZBN71006-87 “Technical conditions of pure bending fatigue testers”. Total 18 specimen is prepared having 9mm diameter and 96mm gauge length with 8.5mm of notch diameter at the center of the specimen and having a total length of 226mm as shown in figure 6 and these all dimensions are according to the fatigue machine standard. For ECAPed sample, assemble is made at the both ends of specimen to maintain the length of 226mm so that it can fit into the machine for testing but the gauge length is same as that as-received specimen.

Figure 5. Four point rotation bending machine

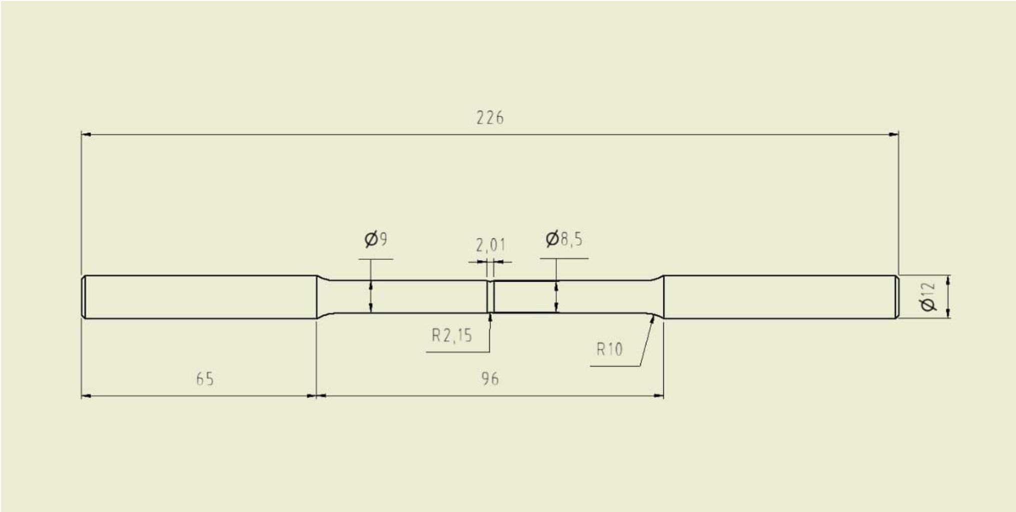

Figure 6. Fatigue sample drawing

Results and Discussion

Notch concentration factor Kt is determined by using FEA software Abaqus. The Model is made having the same dimension as machined sample and have same notch depth. Four point condition is applied to the model and load is assumed which is 80N. In this assumed load, the maximum bending stress came to be 63.37N/mm^2 as shown in figure 7. The without notched maximum stress is obtained by

$$\sigma_{b} = 32M/\pi d^3 \qquad (1)$$

Whereas M is bending moment which is equal to Q a / 2 and d is rooted diameter of notches. After putting the values σ_b came to 55.89N/mm^2 . As notch concentration factor is defined ration of maximum bending stress with notched to the maximum bending stress with notched. Kt is obtained to be 1.140 and it is also verified by using empirical data[13].

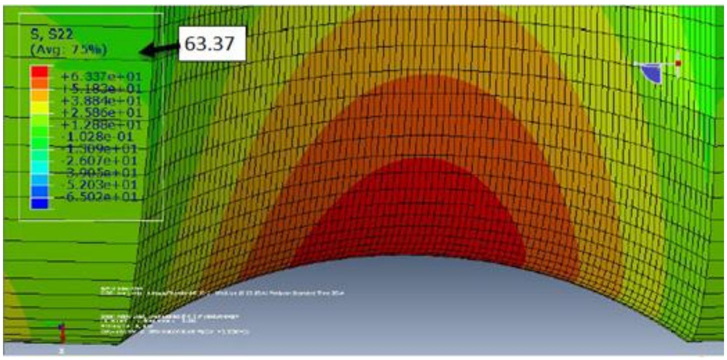

Figure 7. Maximum bending stress at notched sample

After a series of experimentation date is obtained for as received and ECAPed samples. Different load was applied and for each load maximum bending stress with the notch is computed and at each load three trials are performed. The S-N Curve is drawn from obtained data for as-received and ECAP samples as shown in figure 8 and figure 9.

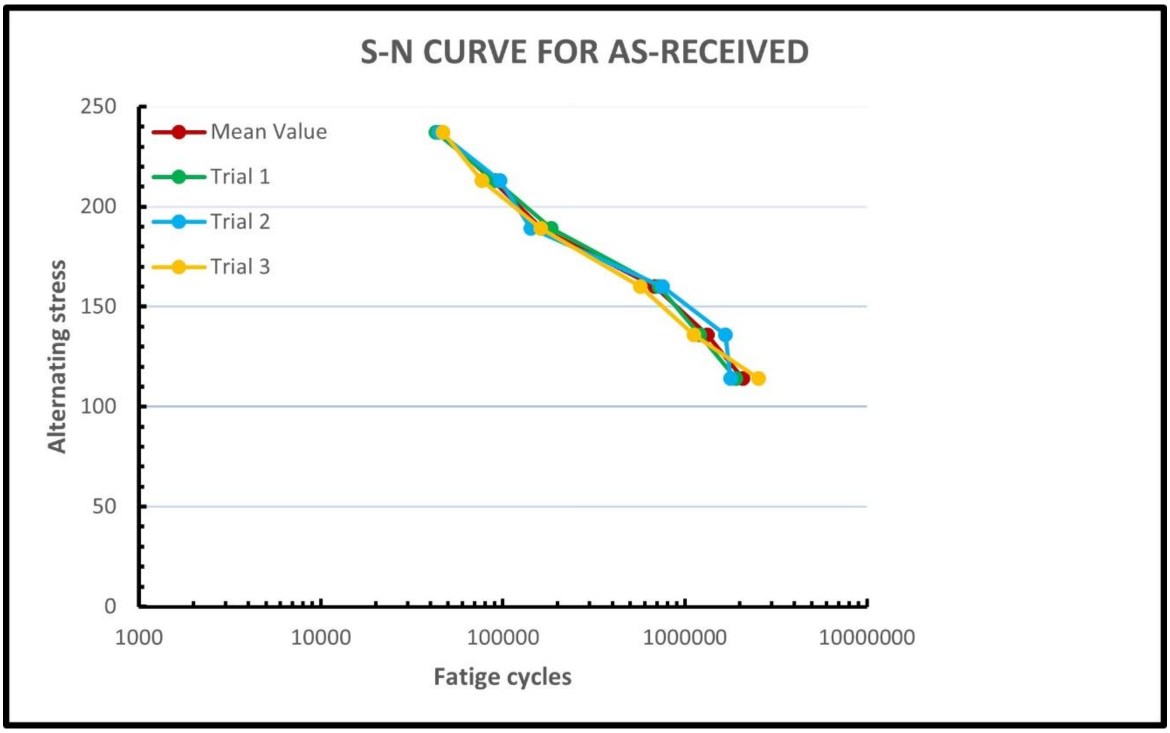

Figure 8. S-N Cure for as-received samples for Trial 1,2,3 and Mean value

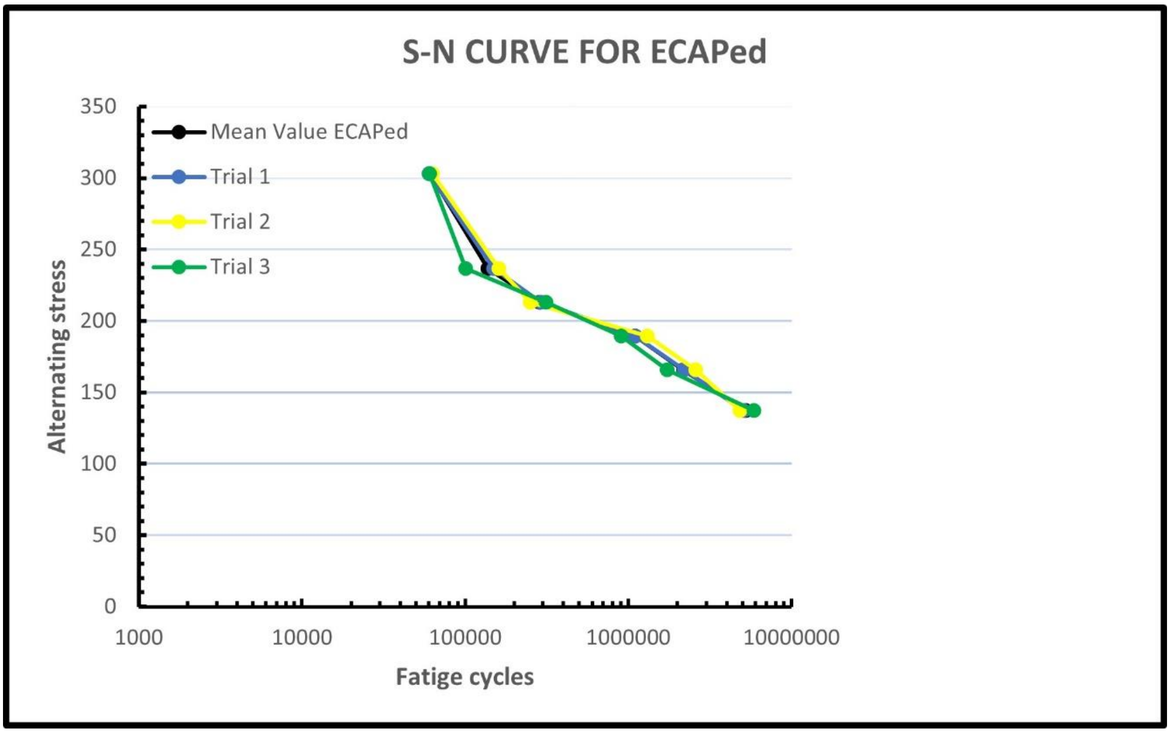

Figure 9. S-N curves for ECAPed Samples for Trial 1,2,3 and Mean value

These graphs depict the S-N curves of as-received and ECAPed Al2024. The fatigue life in this study is based on 10^7 cycles because Al2024 does not have a defined fatigue life. Figure 10 shows how fatigue strength increases considerably after the first pass of ECAP in both low and high cycle regimes. A considerable improvement in fatigue life of Al2024 aluminum alloy occurred which is up to 18.9% during the ECAP process, which was almost entirely attributed to the smaller grain size and increased yield strength of ECAPed specimens compared to as-received specimens. The higher yield stress and smaller grain size of ECAPed specimens limit the number of dislocations in slip bands and macroscopic plastic deformation. As a result, the ECAP procedure enhances the fatigue limit and also increase in hardness and tensile strength. Many investigations have reported this behavior in ECAPed Al alloys [14-16].

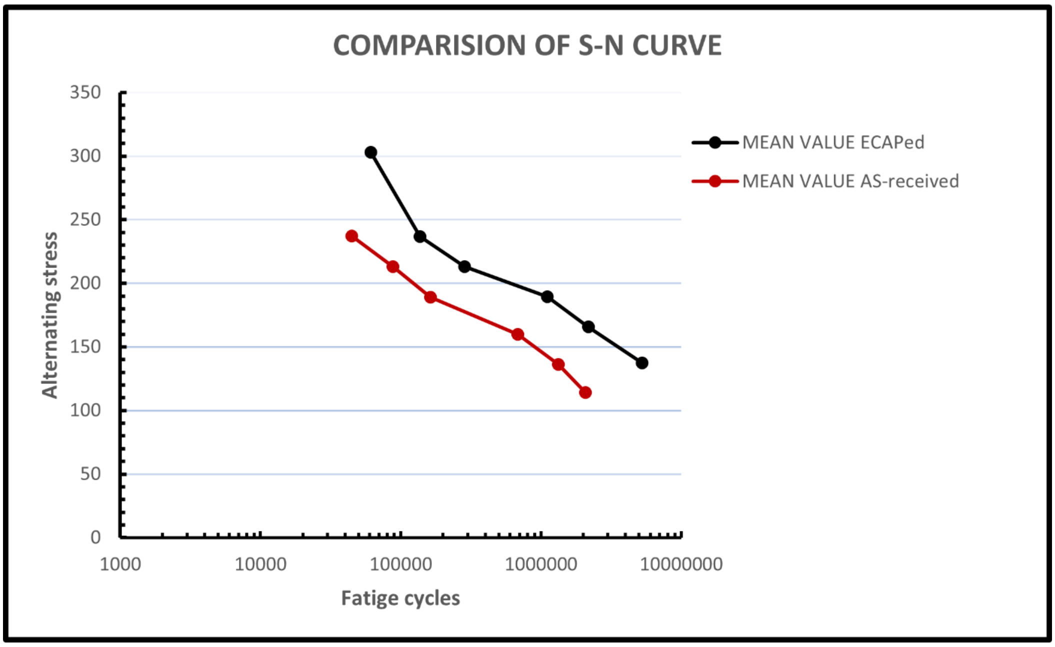

Figure 10. Comparison of S-N curve of as-received and ECAPed Samples

Conclusions

It has been concluded from the result that Aluminum alloy 2024 samples, were severely deformed when passed through die angle of 100^{o} degree at 400^{o}C and there is considerably increased in fatigue strength for both, low and high cycle regime. The fatigue life of the ECAPed sample increases by 18.9% as compared to as-received, indicating a substantial improvement in the fatigue life of Aluminum alloy-2024 processed through equal channel angular passing.

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Nomenclature

ECAP	Equal channel angular pressing
SPD	Severe plastic deformation
ASTM	American society for testing and material
HTIW	High temperature insulation wool
E	Modulus of Elasticity
FEA	Finite element analysis
Q	Load [N]
SN	Fatigue-life
ϕ	Die angle
Ψ	Corner angle
M	Bending moment [N.mm]
D	Diameter [mm]
Kt	Notch concentration factor
σ_b	Maximum Bending stress [N/mm^2]

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