Effects of SPD Techniques on Microstructure Properties of Materials: For Industrial Applications

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Abstract

From last few decades, Severe Plastic Deformation (SPD) Methods practised as a huge scope among the research arena. To maintain the multifunctional properties of material at the same time is difficult job. SPD techniques have found a promising attention by researchers to impart grain boundary strengthening and developing ultrafine grains (UFG) in metals. SPD techniques develop a great attention of the researchers in the field of Materials. In the preliminary phase, SPD techniques were focused on the production of UFG in pure materials. But later several researchers have produced UFG in alloys. Furthermore development of various materials using SPD techniques will give amended and remarkable outcomes grounded on our necessity, several post conducting procedures will also support to enrich the characteristics of SPD processes materials. The present article presented a review about Ultra-fine grained (UFG) material treated by means of various SPD Techniques and discussed the enrichment of the properties while doing this. In future this article provides a help to modern researchers in the field of material properties enhancement techniques and also concluded the some challenges faced by the researchers in materials.

Keywords.SPD, UFG, CR, MAF,ECAP.

1. INTRODUCTION

Currently, tons of attention has been revealed in Nano structure arena having the property of low weight to demand ratio [1]. Aluminium alloy is used in various fields, due to their properties and light weight, aluminium has various alloys series [2]. As per the demand of industry Al alloys are frequently used in various Structural industries because of their property coalescence i.e. formability, corrosion resistance, weld ability, and mechanical properties [1-4]. The major problem faces by the industries to use Al alloys is their lower strength as compared to low carbon steel [5-6]. Mechanical features of particular materials can be amended through refining the alloys of Al series by enhancing the property limits of these materials by changing its grain structure to ultrafine grains [2]. Since strength enhancement of Al alloys for producing Ultra Fined grains (UFG), Severe Plastic Deformation (SPD) Techniques have been broadly introduced [6].SPD is a deformation technique at a minimum degree and maximumforce [7]. In the starting stage, SPD

techniques were focused on making the ultrafine grain in pure materials. But later various researchers have produced UFG in alloys.

2. Severe Plastic Deformation Techniques

Among the various techniques,SPD is very much famous for forming UFG.Process of SPDis defined as metal forming, in SPD large pressure is enforced on a heavy material to create ultra-fine metals as a result providing further potential intended for structural Applications [8-9]. The size of the grains accomplished by SPD is in between 100 to 1000nm. The main objective of generating UFG from SPD is to fulfil the demand of Industries having the demand of light weight and maximum strength for secure and reliable micro-parts and for environmental point of view. In order to produce a UFG in a material without changing its shape and size SPD techniques has been introduced. High angle grain boundaries are usually measured an initial process of producing UFG materials by SPD Techniques [8-9].

2.1 Equal Channel angular Pressing (ECAP)

ECAP is extensively well-known fabrication technique of UFG metals and alloys without the change made in billet size [9-11]. It is noticed for generating the UFG by using the ECAP, strain rate will increases as the temperature increases [12-13]. Operation done by ECAP enhances the substantial strength of material at ambient temperature as long as developed UFG having good thermal stability and providing superior property of higher ductility at high strain rate at elevated temperature [12].

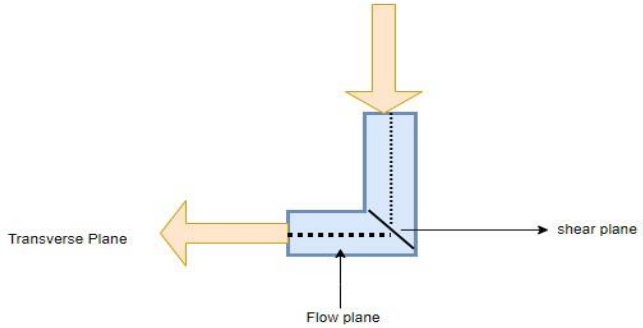

Figure 2.1: Principle of ECAP

Figure 1 gives a basic principle diagram of ECAP in this process a material is compressed through a die at an angle of θ with a corner curvature angle α. In ideal condition it is confirmed that by ECAP, the die is having a homogenous simple shear strain but the applied strain in ECAP is not homogenous as there is a friction force present in between die and material and due to this may change a shear strain in die. The main factors inducing through ECAP method are pressing temperature, load and speed.

2.2 High Pressure Torsion (HPT)

HPT is basically a SPD process as shown in figure 2, for producing the UFG grains in samples through torsional shear strain under a very high hydrostatic pressure [13]. HPT is considered as a more powerful scientific tool to examine the structural and multi-

functional properties of the materials [14]. HPT results the development of UFG with large angle high grain boundaries [15].

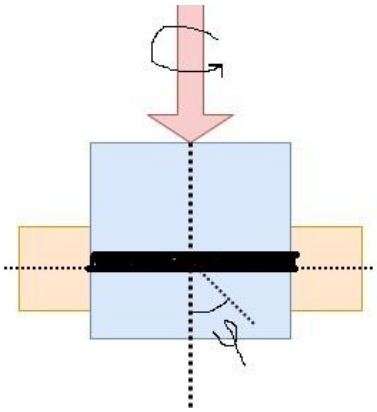

Figure 2.2: Basic Principle of HPT

Figure 2 shows the schematic Diagram of HPT Techniques, contains a combined effects of high pressure with torsional strains. One of the disadvantages of using these techniques is that only produced small samples of coin shape having the diameter of 10 to 15mm and thickness of 1mm only [16]. HPT techniques are size restricted and due to having this property it is mostly used for research investigation. One more vital problem going on HPT is non-uniform deformation [17]. It is highlighted by various researchers that HPT techniques are nearly difficult to create a perfect HPT distortion as of disarrangement of anvil axes [18].

2.3 Accumulative roll-bonding (ARB)

ARB was introduced in the year of 1998[19].This processes were introduced to overcome the problems produced while doing the processes in HPT and ECAP like low production, small sample size and latter size. Author [19], describes the techniques such as the metal sheet is rolled up to 50% reduction in thickness at that time the rolled sheet is divided into two parts and both parts are fixing with scrubbing a and wire brushing, hence thickness of the sheet brings back to its original state. Sheet metal rolled up to 50% thickness reduction and then sheet is divided into two parts and both parts are stacked together by preparing the contact surfaces with degreasing and wire brushing, thus restoring the original thickness of the sheet by Saito et al [19].

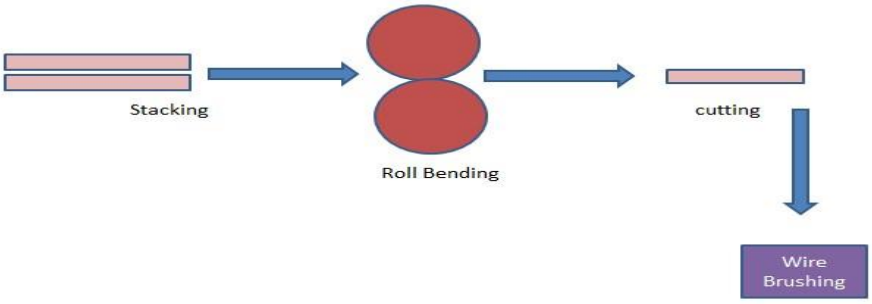

Figure 2.3: Basic Principle of ARB

2.4 Multi-axial forging/ Multiple Direction Forging (MAF/MDF)

For the grain refinement MDF was first introduced in 1990s [20-21].MAF is also known as MDF in this forging force are work under three equilateral ways. Because of temperature intervals ($0.1T_m$ -$0.5T_m$) the refinement of grains in MDF is generally accompanying with dynamic grain transformation, Where Tm is melting temperature. This techniques can be used for manufacture the large size billets having UFG structure [22].

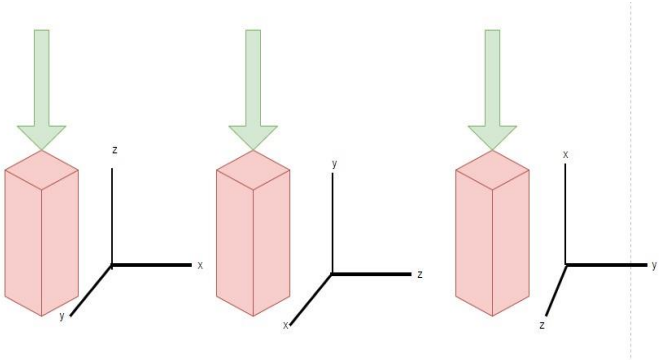

Figure 2.4: Multi Axial Forging System

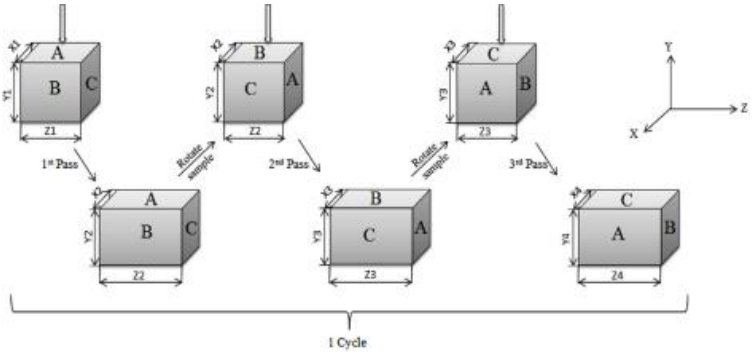

Figure 2.5: Phases of MDF in direction x, y and z[23]

2.5 Cryorolling (CR)

Deformation at Cryogenic is usually used to development of UFG structure in the materials. As todays demand Aluminium is one of the demanding materials in various industries due to their remarkable low weight to high strength. Almost 46% aluminium alloys are selectedby industries for the applications but challenging task to maintain the properties in the alloys, CR serve a potential path in this [13]. Cryorolling is basically low temperature rolling process which required low load to form severe strain in materials, causing micro crystal structural characteristics. Deformation at low temperature has established a probable methodology for formulating UFG/NG materials having an excessive disorder concentration for add-on Mechanical characteristics. The enthusiasm of using Cryogenic Process is to enhance the ductility of the material.

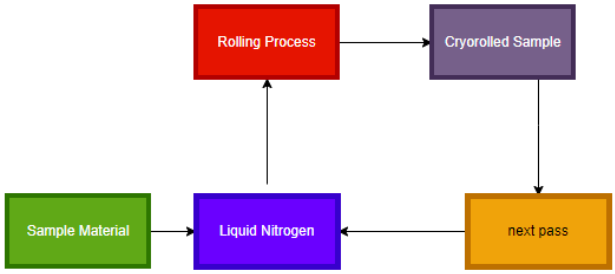

Figure 2.6: Flow Diagram of Cryorolling Process

2.6 Twist Extrusion

It is a deformation technique like others processes and it was first introduced by Beygelzimer et al [24-25]. This process is just like an extrusion process where a billet is extruded over a twist die. The benefit of using this one is its high expanded volume. Unreliable distortion is main limitation of using this process as encountered in HPT, where lesser distortion occurred nearby the extrusion axis. Furthermore it is observed by researcher that this process is not proficient than ECAP or HPT [26].

3. Effects of various SPD techniques on different Materials

As per the discussion it has been clear that SPD techniques are used for imparting the grain boundaries andstrengthening and developing ultrafine grains (UFG) in metals. While doing the experiments it is observed by various researchers that most of the cases when the strength of the materials enhanced in that particular time the ductility decreases but for Age-Hardenable alloys, at the same time there is a edifice enhancement of strength and ductility but in case of Non-Age Hardenable alloys, there is no development of strength and ductility. The observation made from table is while single ECAP process is done by researchers there is no up gradation of strength and ductility but when ECAP processed with Cryo treatment shows a strength and ductility enhancement. Creep behaviour of the material influence by the passes being processed by ECAP as observed by researchers. As ECAP followed by Annealing also shows the transformation of grains which promotes material thermal immovability. Observation made by researcher that on SPD with parallel channel and it is observed by researchers when SPD-PC combined with one matrix of

direct extrusion in non- axisymmetric section that will give an improved microstructure with enhanced mechanical properties [57].

Table 1: Properties of Materials during SPD techniques at several conditions

S.No	Techniques	Material	C.Y.S(MPa)	Ultimate Tensile Strength (MPa)	Elongation	Endurance Limit(MPa)	Ref.
1	HR and ECAP, ST+ECAP+ Q	AZ31	115 180	251 286	27 9.5	95 40	27 28
2	ECAP	AA1050	-	-	-	50-55	29
3	ECAP at 150°C ECAP + annealing at 200°C	AA5052	394 350	421 370	9 10.5	- -	31 30
4	ECAP at 150°C ECAP at 110°C	AA5056	280 392	340 442	25 7	116 116	30
5	ST at 350°C and ECAP at 200°C	AA5053	276	352	20		32
6	ECAP and Hot Rolling	AA7075	650 240	720 375	8.4 29	- 150	33
7	ST+ECAP+ Ag at 190°C for 4hrs	AA6106d + 0.1Zr + 0.5Sc	570	590	9	225	34
8	CR ECAP at 400°C	Ti (grade 2)	380 640	460 810	26 15	240 380	35
9	CR 87% ECAP at 400°C	Ti (grade 2)	970	1050	8	420	36
10	CR	Ti (grade 4)	530	700	25	350	37
11	ECAP	Cu	375	385	-	170	38
12	ECAP and Aging at	Cu-0.36C	438	454	23	180	39

	500°C , 1hrs	r					
13	ECAP+PC	Al6063 alloy	210	230	8	-	57

4. Discussion on properties followed by of SPD Techniques

4.1 Strength and Ductility

Table 1 shows, "strength and ductility" are an important property of the materials. Properties of material are actually liable on the grain size because these actually affected by the SPD techniques used, more than any other Mechanical Properties. Besides, a lot of of the properties are unswervingly administered using the ductility and strength [33]. It's very challenging to serve ductility and strength at the same time of the operation. When strength enhances the ductility of the material reduced as most of the cases shown in table 1. Loss of ductility comes from the combined effect of high flow stress and low strain hardening. It is observed by the researchers that for Age hardenable alloys, there is a structure improvement with strength and ductility but in Non-Age hardenable alloys, there is no improvement in strength and ductility [35]. It has been shown that elongation through SPD techniques does not improve however plastic increases flow. While using only ECAP not improves the ductility and strength but ECAP followed by Cryo treatment will tremendously increases the strength and ductility of the material [37-38].

4.2 Fatigue and Creep Behaviour

Fatigue and Creep Behaviour of Material is also important after Strength and Ductility property and to analyse this property of the material is not easy too. By the Previous research it has been observed that the Fatigue behaviour of material does not exhibit the stronger grains [40-42].After doing research it has been observed that when ECAP process combined with other Temperature Mechanical processes that will results the fatigue of UFG metals. There is less research in the field of Creep and Fatigue of UFG material Produced by SPD Techniques [9]. Many Researcher put emphasis on factors which shows the effect of creep on materials processed by ECAP technique [43-45].By the experiment it has been observed that creep Behaviour of the material depends upon the number of passes. It owes to the number of influences counting microstructural deviations,coalesce of Microstructure and Nano porosity prompted through ECAP.

4.3 Thermal stability

Along with strength and ductility, thermal Stability is also important parameter. To maintain various property of the material at the same time is very difficult.According to the needed application of the material, a complete list of properties has to be maintained [46].From the research it has been investigated by researcher that most of the cases SPD treated material i.e.oxygen free copper offers poor thermal stability [47-48].Many experiments has been done to improve the thermal stability with multi-functional properties of the materials. It is clearly shown in Experiments Recovery rate is depends on the number of ECAP passes [48-49]. Copper manufactured from SPD shows a low thermal stability as there is no change in microstructure but when the temperature gets increases normal grain growth takes place and after doing annealing it is shown by experiments there is a transformation of UFG grains into Coarse Grains [50]. To overcome this

limitation and for maintain the multifunctional properties in SPD various processes has been introduced like grain refinement, strain hardening, solid solution hardening and precipitation hardening [48-51].

4.4 Corrosion Resistance

On behalf of future engineering prospects, Corrosion resistance is an important property and to maintain all the property of the materials is challenging task too [52]. The property of corrosion in a single phase in metals is predominantly influence by grain size [53]. Corrosion in a material could be take place in the aspects of pitting, chemical, electrochemical, stress corrosion cracks (SCC) and corrosion fatigue [52-54].From the investigation it is noted ECAP techniques gives a better decision by increasing the Mechanical properties of the material it also enhance the SCC and corrosion fatigue resistance [55-56]. Problem is faced by various researchers while examining the effects of SPD on corrosion behaviour of Magnesium due to the processing temperature while doing SPD [58-64].

5. Conclusion

From the above research it has been perceived that numerous research has been focused on the properties like Strength and ductility but at the same time to maintained the overall properties of the material is very difficult, By using SPD with some post processes the properties of the materials can enhanced. This paper gives a brief history about SPD techniques, their approaches and assets of SPD processed UFG materials. This content will also help the researchers as a summary of SPD techniques.This is also providing a Basic knowledge of problems face by various industrial applications. A large number of concept is developed by various researched but somehow justification is missing in some concepts. However it also gives the relationship between strength ductility balanced by using SPD techniques. The improvement of Corrosion resistance and thermal stability has been carried out by using SPD techniques if the number of ECAP passes will increase. SPD technique mainly extended from Conventional metal working methods as this is further established for handling bulk materials. Now days this technique is further used for various purposes like compaction of powders, for developing alloys etc.

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