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Investigation of mechanical properties on composite materials by several of severe plastic deformation (SPD) methods

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Abstract. The technology of severe plastic deformation (SPD) is the process on forming metals of large plastic strain that is used for mass production in order to make ultrafine-grained (UFG). Through research on the characterization of aluminium-based composite materials with several SPD methods, the ideal variable will be obtained in producing high-strength materials. The development of a new SPD method driven by requirements simplifies the process, so that it can be applied for mass production, some of the development of SPD technology is able to produce high plastic strain. The market for nanostructured materials produced by SPD technology is in sectors where superior traits such as specific strength is needed. This research is focused on a comparison of several SPD methods; APB, MAF, ECAP-PC and RPRF, in the scope of mechanical characterization on aluminium based composites. Result of mechanical properties obtained, the RPRF method is the best that is able to produce higher mechanical characteristics than other methods. That produces 75.9 VH10 hardness on RPRF, while APB 45.82 VH10, ECAP-PC 66.12 and MAF of 42.9 VH10

1. Introduction

The development of material processing at this time leads to the technology of severe plastic deformation (SPD) [1]. SPD is the new process of forming that is developed by some researchers to considerable plastic strain by applying high pressure to obtain bulk on ultrafine grained (UFG) materials. The three methods that were developed in the SPD were equal channel angular pressing (ECAP) by Segal *et al* [2], high pressure torsion (HPT) by Valiev [3] and accumulative roll bonding (ARB) initiated by Tsuji [4]. ECAP process has the ability to introduce significant grain refinement into large bulk samples. Typically, it reduces the grain size into the sub-micrometre level, and thereby it produces materials which are capable to give unusual physical and mechanical properties. ECAP combines compressive and tensile stress in the mold/dies to generate products with severe deformation [5]. The principle of the HPT processing is that a sample in the form of disc or ring has been placed between two anvils which were rotated with respect to each other under application of compressive pressure to create torsional strain in the samples [6]. Furthermore, ARB is the process of rolling material by stacking sheet material [7]. It has a potential for becoming an industrial process of producing UFG on metal sheets which have grain sizes larger than a few tens of micrometres [8]. During the last two decades, the SPD methods have been developed rapidly. New methods simplify the process or enable producing materials with high mechanical properties. Some examples of new developments in the SPD methods were



accumulative press bonding (APB). It was requiring 10-16 cycles to produce high mechanical properties. The last SPD method is repetitive press roll forming (RPRF) process that combines uniaxial press and compression rolling force [9]. This paper describes the mechanical properties by some of SPD methods like APB, ECAP-PC, MAF, and RPRF. Several methods will be compared among SPD processes with each other that has a goal to get the match between the process of SPD and materials.

2. Materials and Experimental Methods

The materials used on experiment were metal and ceramic. Each type of process in the SPD method uses different types of matrix and reinforcement. The use of composite materials processed in SPD has been presented in Table 1 to clarify the use of materials in the SPD process. In Table 1 shown various types of aluminum that were used and several types of reinforcement for materials-based composites of SPD process. Also, some explanations of the methods used were APB, ECAP-PC, MAF and RPRF presented Figure 1.

Table 1. Use of materials-based composites of SPD process.

SPD Process	Stress (MPa)	Temperature (°C)	Materials	
			Reinforce	Matrix
ECAP-PC	450	400-500	Al ₂ O ₃	AA1100
APB	350	350-400	Al ₂ O ₃	AA1100
MAF	400	300-400	SiC	AA5052
RPRF	250 ^a +150 ^b	300-450	SiC/Al ₂ O ₃	AA1100

^a Maximum stress pressures of pressing. ^b Maximum stress pressures of rolling.

2.1. Accumulative Press Bonding (APB)

The APB process has been used as a novel technique to provide an effective alternative method for manufacturing of aluminum based composites. APB was performed in two stages [10]. To achieve a good dispersion of Al₂O₃-nanofibers (ANF) as reinforcement particles, between strips, an acetone-base suspension was prepared and put under ultrasonic waves. After surface preparation, ultrasonicated ANF particle in acetone was sprayed between the two aluminum strips with an atomizer. Then, ANF particles deposited and acetone evaporated in air, so that the brushed surface of one strip uniformly covered with ANF particles. Afterward, two strips were put on each other and stacked. The cold press bonding process was performed on the stacked strips with no lubrication, employing a laboratory hydraulic press machine with a loading capacity of 350 MPa. The APB process scheme has been explained in Fig. 1 a, for processing aluminum based composites with ANF as a reinforcement.

2.2. Equal Channel Angular Pressing (ECAP) Parallel Channel

The principle process of ECAP-PC is the work of simple forces consecutively, in two bend of deformation zones on the dies, which correspond at two consecutively arranged zones of intersecting channels in the tools. ECAP-PC is a relatively new modification procedure from conventional ECAP [11]. The reinforcing material uses Al₂O₃ wrapped in a copper capsule, then Al₂O₃-reinforced aluminum is heated at a temperature range of 400-500°C, after which the composite samples are pressed with a hydraulic engine of 450 MPa.

2.3. Multiaxial Forging (MAF)

MAF principle that is after forging, material rotated 90°, the forging up to several times pass on each side. Pressing on each side has an effect to make the pressure is evenly distributed, so that strength increases on each side [12]. The initial stage is cutting the matrix material plate AA1100 with a size of 135 mm x 25 mm x 3 mm thickness 3 mm. The sample is brushed using a wire brush with the same

direction, the material is cleaned using an acetone solution then the grinding process is carried out. Acetone is given to avoid dirt and oxidation [13]. Pre-heating uses a temperature of 300-400°C for 1 hour, after that MAF emphasis uses a hydraulic press with a maximum loading of 100 kN. The MAF process is carried out in 5 passes with a rotation direction of 180° with almost final reduction reaching 50%. the initial thickness of the material before the MAF process is carried out at 6 mm and the final thickness after the MAF process reaches 3 mm.

2.4. Repetitive Press Roll Forming (RPRF)

RPRF is part of SPD methods with the aims of process to simplify the process steps of pressing and rolling on composites materials type. Due to the evolution of grain to produce a uniformly good mechanical properties, it is required compression cycle between 10-16 times, however with RPRF methods between compressive load and roll. It delivers a uniform grain and superior mechanical properties [14]. In this RPRF process, it applied two types of style applications. First the compression on the workpiece uses a press machine, to tie the two plates that are processed. And then it continues to the rolling process to reduce the plate thickness.

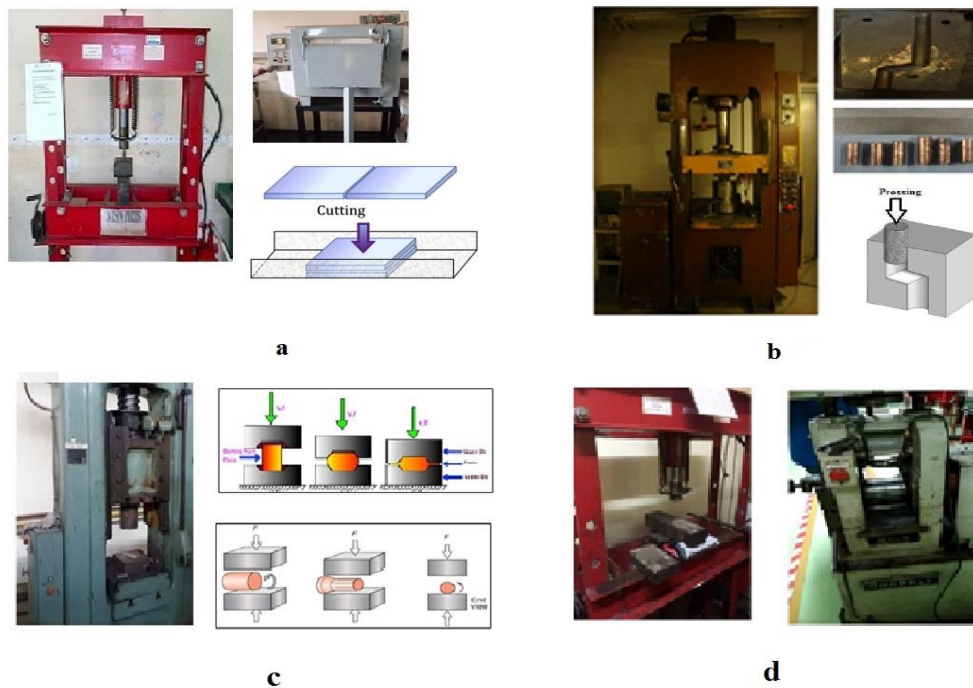


Figure 1. Process of severe plastic deformation Methods: a) accumulative press bonding (APB) b) Equal channel angular pressing (ECAP) - parallel channel c) Multi-axial forging (MAF) d) Repetitive press roll forming (RPRF) process.

3. Characterization of Properties

The mechanical properties that was tested was VH10 of hardness. Some of the resulting from SPD process consist of mechanical properties results of the APB, ECAP-PC, MAF and RPRF. Microhardness measurements reveal the mechanical properties of hardness [14]. Hardness reviews the ability of metal/material to withstand the burden of plastic deformation, for application of strength which is widely used for materials that have hardness [11-12]. Comparison of the hardness of SPD technology has variations, the APB process produces an average hardness: 45.82 VH10, in the ECAP-PC process the average hardness increases by 66.12 VH10. In the MAF process the hardness tends to decrease to 42.9 VH10. Optimal hardness is the result of an RPRF process, reaching of 75.9 VH10. The values of hardness variance are presented in table 2. The APB process used as a novel technique in this study that

provides an effective alternative method for manufacturing of composites materials, this process was developed based on the principle of accumulative roll bonding (ARB) process, but can be readily installed in both a laboratory and industrial environment [10]. Pressing of ECAP-PC has an effect on microstructure and mechanical properties of the composite materials. The principle work of ECAP-PC is the application of simple forces consecutively in two bend of deformation zones on the dies, which correspond at two consecutively arranged zones of intersecting channels in the tools [11]. Addition of SiC on MAF process is to increase strength greater than the base material. MAF for processing Al/SiC based composites to get of distribution of precipitate evenly in matrix and change of mechanical properties after MAF process. Therefore, variation of weight fraction of SiC and pre-heating temperature were conducted [13]. The development of the latest methods that refine the ARB and MAF processes are repetitive press roll forming (RPRF). RPRF is a process of SPD that combines repetitive pressing forces with the rolling forces, where the compression procedure is done continuously to meet the cycle's [15]. Compression on the RPRF process has two important roles in the processing of composite materials; First pressing force gives effect to the embedded of the reinforcement, either powder or fibers into the surface of the sample plate, so that there will be a face bond between the matrix and the coupled reinforcement, latter of the roll force providing contact on the surface which will result in the distribution of the reinforces dispersed into the composite contact plan [12].

Table 2. Results comparison of Hardness on SPD technology, with the latest methods: APB, ECAP-PC, MAF and RPRF.

Composites Materials	APB (VH 10)	ECAP-PC (VH 10)	MAF (VH 10)	RPRF (VH 10)
AA1100/Al ₂ O ₃	39.5	46.7	43	74.6
AA1100/Al ₂ O ₃	47.2	52.6	45.6	76.8
AA5052/SiC	51.5	69.3	41.4	74.7
AA1100/SiC	45.1	73.6	40.7	78.3
AA1100/Al ₂ O ₃	45.8	88.4	43.8	75.3
Total Value	45.82	66.12	42.9	75.9

When compared in a process, some SPD methods that have the application of different styles from the applied force will result in hardness values. In the application of the APB force, compressive stress will have an effect on the resulting deformation, hardness is the result of strong bonds formed from pressure on the microstructure. Figure 2 a. showing the result of processing APB without reinforcement, the microstructure of the material is seen squeezing the interface, but after adding the reinforcement in fig. 2 b, the reinforcement of Al₂O₃ is distorted on the surface, this will inhibit the formation of grain bonds, resulting in relatively low hardness. The results of processing ECAP-PC interface are produced by the friction force between the *dies* and the side on the material, so that the material is well distributed, as presented in figure 2 c. After adding Al₂O₃ in figure 2.d, there is an indication of micro uniformity on the middle side.

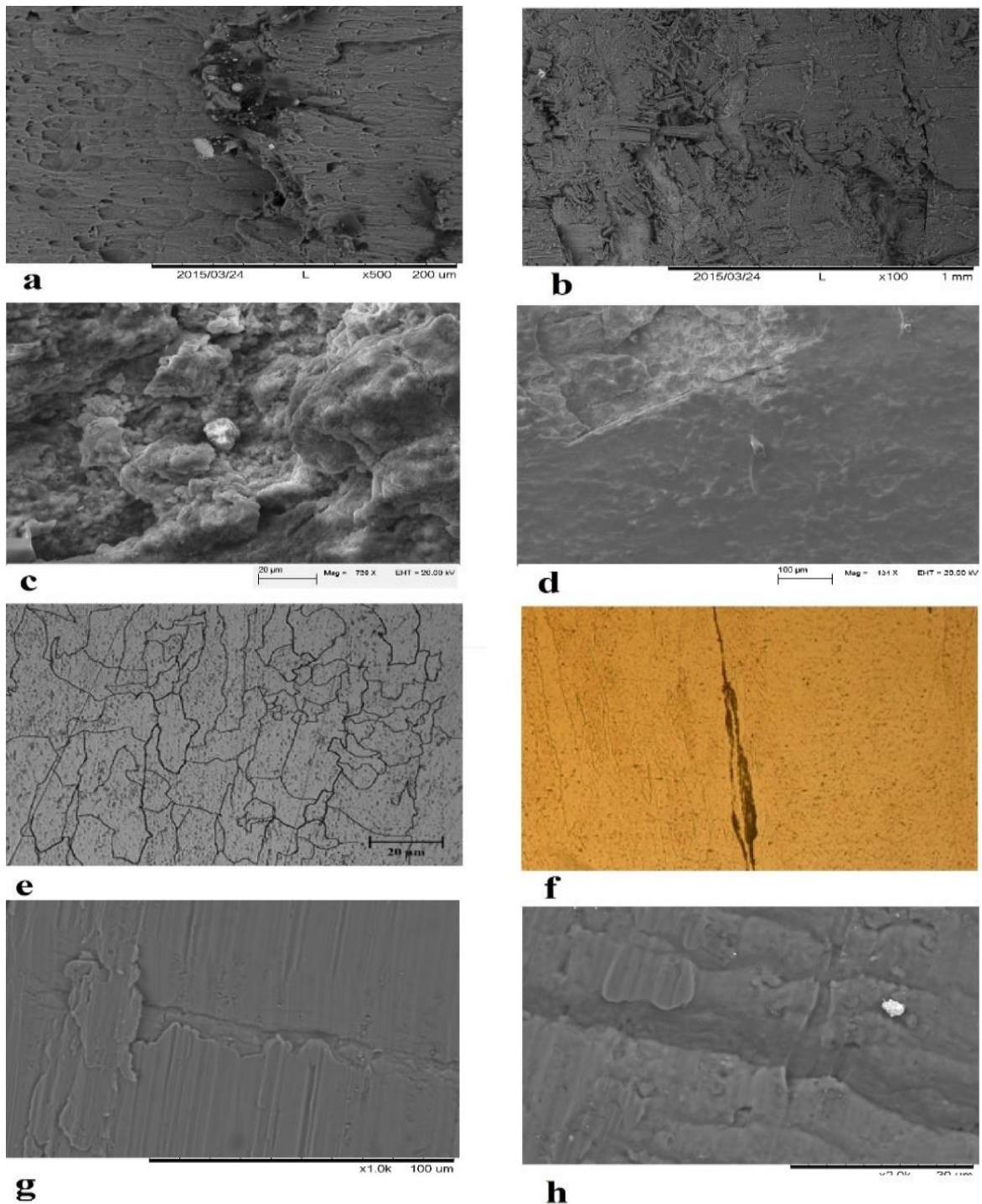


Figure 2. Micro-structure of the results of the SPD process: a) Aluminium no-reinforcement processed by APB b) Aluminium reinforced Al_2O_3 processed by APB c) Aluminium no-reinforcement processed by ECAP-PC d. Aluminium reinforced Al_2O_3 processed by ECAP-PC e) Aluminium no-reinforcement processed by MAF f) Aluminium reinforced Al_2O_3 processed by MAF g) Aluminium no-reinforcement processed by RPRF h) Aluminium reinforced $\text{SiC}/\text{Al}_2\text{O}_3$ processed by RPRF

MAF process is a process that applies compressive forces uniformly on each side, MAF is applied with a back and forth compression style from all sides, using 90-180° angles. See figure 2 e, the grain distributor is almost uniform before the reinforcement is added. After adding the SiC as reinforcement in fig. 2 f, a boundary line is formed which separates grains from one to another. The using of Al₂O₃ and SiC as a hybrid composites on RPRF process is processed to see the effect of mechanical properties. Principles on RPRF process, uses two types of style, namely compression force and compression roll loading. The process of pressing, particle line on the face bond will disappear, but not all the particle line is lost because it is blocked by the presence of reinforcements in either SiC or Al₂O₃.

4. Conclusion

The APB process produces an average hardness of 45.82 VH10. The results of the APB hardness were not significant because in the microstructure there were still mutations in the grain and this was identified as stress concentration due to the effect of compression. Results hardness of ECAP-PC was 66.12 VH10. It has an effect on microstructure and mechanical properties of the composite materials. The principle of work on the process were the application of simple forces consecutively in two bend of deformation zones on the dies which correspond at two consecutively arranged zones of intersecting channels in the tools. Hardness result of MAF process tends to decrease to 42.9 VH10. Addition of SiC on MAF process has increased the strength greater than the base material. It was processing Al/SiC based composites to get of distribution of precipitate evenly in matrix and change of mechanical properties after MAF process.

Optimal hardness value is resulted in RPRF process that has a value of 75.9 VH10. The use of Al₂O₃ and SiC as hybrid composites in the RPRF process has a advantages to improve the properties. In the RPRF process, particle line on the face bond will disappear but not all the particle line is lost because it was blocked by the reinforced of SiC or Al₂O₃ where the rolling process gives the effect of grain fineness.

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References

- [1] Valiev R Z, Langdon T G 2006 Principles of equal-channel angular pressing as a processing tool for grain refinement. *Progress in Materials Science*. **51** 7, **881-981**
- [2] Segal V M, Korbel A, Richert M and Richert J 1999 Second RISO International Symposium on Metallurgical Science, *Material Science Engineering* **A271** 322
- [3] Zhilyaev AP, Lee S, Nurislamova GV, Valiev RZ, Langdon T.G 2001 Microhardness and microstructural evolution in pure nickel during high-pressure torsion *Scripta materialia* **44** 12 pp. 2753-2758
- [4] Saito Y, Utsunomiya H, Tsuji N, Sakai T 1999 Novel ultra-high straining process for bulk materials development of the accumulative roll-bonding (ARB) process. *Acta Materialia* **47** 2 pp. 579-583
- [5] Pramono A, Kollo L, Kallip K, Veinthal R, Gomon JK 2014 Heat treatment of ultrafine grained high-strength aluminum alloy *Key-Engineering Materials* **604** pp. 273-276
- [6] Alhamidi A.A, Edalati K and Horita Z 2013 Production of Nanograined Intermetallics using High-pressure Torsion. *Materials Research* **16** 3 pp. 672-678
- [7] Pramono A, Kollo L and Veinthal R 2015 Microstructure of AA7075 based composite by accumulative roll bonding (ARB) process. *Advanced Materials Science and Technology* **1123** pp. 114-118
- [8] Pramono A, Kollo L and Veinthal R. 2016 Hot and cold regions during accumulative roll bonding of Al/Al₂O₃ nanofibre composite. *Proceedings of the Estonian Academy of Sciences* **2** 65 pp. 132-137.

- [9] Pramono A 2016 Investigation of Severe Plastic Deformation Processes for Aluminum Based Composites. *Ph.D. Dissertation*. Department Mechanical Engineering. Tallinn University of Technology., Tallinn-Estonia
- [10] Amirkhanlou S, Ketabchi M, Parvin N, Khorsand and Bahrami R. Accumulative press bonding; a novel manufacturing process of nanostructured metal matrix composites. *Materials and Design* 2013; **51**, pp. 367–374.
- [11] Pramono A. Dhoska K. Markja I. Kommel L 2019 Impact Pressure on Mechanical Properties of Aluminum Based Composites by ECAP-Parallel Channel. *Pollack Periodica-An International Journal for Engineering and Information Sciences*, **14** 1 pp. 67–74.
- [12] Pramono A. Jamil AM. Milandia A. Aluminum based Composites by Severe Plastic Deformation Process as New Methods of Manufacturing Technology. *MATEC Web of Conferences* 2018; **218**, 04011, pp. 1-9.
- [13] Pramono A. Yolanda A. Alhamidi AA 2019 Pre-heating of multi-axial forging (MAF) on aluminum based composites. *IOP Conf. Series: Materials Science and Engineering* **478**, 012029, pp. 1-6.
- [14] Valiev RZ. Parfenov EV. Parfenova LV 2019 Developing Nanostructured Metals for Manufacturing of Medical Implants with Improved Design and Biofunctionality. Materials Transactions, special Issue on Severe Plastic Deformation for Nanomaterials with Advanced Functionality, *The Japan Institute of Metals and Material* **60** 7 pp. 1356-1366.
- [15] Pramono A. Merging method of aluminum fiber composite materials with alternating pressure and rolling process using repetitive press roll forming (RPRF). Patent Application: 001/P/HKI/2000. P00201709889. University of Sultan Ageng Tirtayasa Banten, 2017.