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THE EFFECT OF ROLLING CYCLES AND SETTING DIRECTION OF THE REINFORCEMENT ON ALUMINUM BASED COMPOSITE BY REPETITIVE PRESS ROLL FORMING (RPRF) METHODS

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ABSTRACT

Development of technology shown rapid progress in several of structural applications especially on advanced of component in industry. Using of aluminum as a matrix on composite fabrication by addition ceramic as reinforcement is the better solution, for expected to improve the mechanical properties on materials-based composites. The process carried out was combining SiC particles with an aluminum (AA1100) as a matrix with variations number of rolling cycles: 2, 4 and 6 as direction. Preparation of SiC particles with transverse, cross section and mix variations through a hot working process with the technology of severe plastic deformation (SPD) using the method of repetitive press roll forming (RPRF). The results obtained was mechanical properties increased when the roll cycles high with mix of variations in the direction of SiC arrangement resulting in a wider distribution of SiC into the matrix AA1100. Rolled process by cycle 6 and the direction of the SiC mix resulted in higher hardness of 55.54 HV, tensile strength was 90.46 MPa, porosity 0.33% density 1.831 gr/cm^3 and SiC distribution 23.19%. Increasing the number of rolling cycles, the thickness of the interface for the formed layer and the size of SiC particles will decrease due to SiC particles scattered in most aluminum matrices, which can increase the hardness value.

Keywords: *Composites, AA1100, SiC, RPRF, Rolling direction and Interface Bonding.*

INTRODUCTION

The developments of materials technology shown rapid progress, in various industrial component applications. This creates many opportunities for innovation in improving the quality of materials for industrial production. Technology in composite manufacturing has also evolved from the casting process to the deformation process (Pramono. A, 2017). The new technology of manufacturing process by severe plastic deformation (SPD) has been developing rapidly as a processing of metals and alloys. By high pressure there will get ultrafine grained (UFG) in the material which will lead to the increase of mechanical properties. Some of SPD technologies, such as equal channel angular pressing (ECAP), multi axial forging (MAF) and accumulative roll bonding (ARB), have been used for the development of composite materials. To produce high mechanical properties on SPD required a long pressure of cycles. The development of the latest methods that refine the ARB and MAF processes is 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 [Pramono. A, Patent. 2017]. 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 (Pramono. A, 2018).

Aluminum matrix composite (AMC) is a composite with aluminum matrix combined with reinforcement in the form of ceramic-based material to improve the properties of the component of automotive (Palanikumar. K, 2007). AMC materials on several components are required to be able to be applied at high stress, such as in the automotive sector as drive shaft and piston components. Aluminum matrix composites are mixed composite materials which has strength, ductility, density, heat properties and electrical properties can be controlled (Singla, et al, 2009). The ceramic-based reinforcing material that is often used on AMC is SiC (silicon carbide). SiC has a lower density of 3.2 g/cc and young modulus greater than 410 Gpa compared to other reinforce material (Luthfi and syukron, 2010).

Metal matrix composite (MMC) now an understanding as potential material candidate in the variety of structural application such as: aerospace, transportation, military, and even the sports industry because it has good mechanical properties (Hashim. J, et al 2002). Composite fabrication by aluminum as a matrix and addition ceramic as a reinforcement is the right solution, it is expected to improve material properties.

SPD is a technology development system which is one of the processes to produced ultrafine-grained structures in metals and alloys, which have different crystallographic structures (Zrnik. J, 2008). The general of plastic deformation process can be defined as processes that cause very high plastic strain on the metal to produce refined grains with a 1μm grain size (Srinivasa. R, 2011).

RPRF is a process of SPD with adds the back and forth compressive stress to the rolling process. Compressive loads can be produced composite materials that have strong surface bonds by reducing porosity, the purposes of the rolling bond process to produce uniform grain distribution. This method is a modification of ARB with the addition of repetitive pressing has the potential to become an industrial process that produces ultrafine-grained (UFG) composites and materials (Pramono. A, et al, 2016). The ARB and repetitive pressing process requires many cycle's that are repeated in the process. RPRF is able to simplify the number of roll and press cycles with optimal results on interfaces bonding, hardness values, tensile strength, and low porosity density. The RPRF method provides different loading to produce optimal mechanical properties by adding ceramic reinforcement particles to the aluminum composite. In the study of Agus Pramono et al. aluminum using the ARB process without reinforcement in cycle 2 has a hardness of 40 HV.

This study used variations in the number roll cycles (2,4 and 6 cycles) with the addition of 0,4 % SiC and the direction of SiC particles formation based on transverse, cross section and mix direction, in the aluminum matrix with 50% roll reduction. The number of cycles to find out the interface bonding formed on the matrix and the variation in the direction of SiC particle using the RPRF method to determine how optimal the SiC distribution is in the matrix of each cycle. Aluminum combined with ceramic SiC as reinforcement produce very fine grains and forms bonding interface bonds (Pramono. A, et al, 2015). The results will be determined by optical microscope observation, density, porosity, hardness test, and tensile testing, to find out how optimal the roll cycles and process was carried out.

EXPERIMENTAL METHODS

In this study, aluminum based composites was used as material with measurement of 100 x 20 mm with a thickness of 2 mm. Then the Initial characterization of the sample is done to obtain data before the process is carried out. Addition of SiC ceramic reinforce in the sample by varying the direction of SiC (silicon carbide), namely, transverse, cross section and mix combining transverse and cross section, with weight percent 0.4% wt, pre-heating at 350^{o}C, then repetitive pressing loading of 10 tons, after that it is pre-heated again with the same temperature then rolling with the 50% size reduction 2, 4 and 6 times by 140 tons of forcing.

Table 1. Code of Composites Samples

Sample	Variation Of Cycle	Variation Of SiC Direction
TS2	2 Cycle	Transverse
TS4	4 Cycle	Transverse
TS6	6 Cycle	Transverse
CS2	2 Cycle	Cross Section
CS4	4 Cycle	Cross Section
CS6	6 Cycle	Cross Section
MX2	2 Cycle	Mix
MX4	4 Cycle	Mix
MX6	6 Cycle	Mix

The characterization of the material is carried out by continuing the analysis of the interface bonding, the microstructure with optical microscope, SiC distribution is using the Image-J application, analyzing the hardness using hardness test (HV) and analyzing elongation and strength using the tensile test.

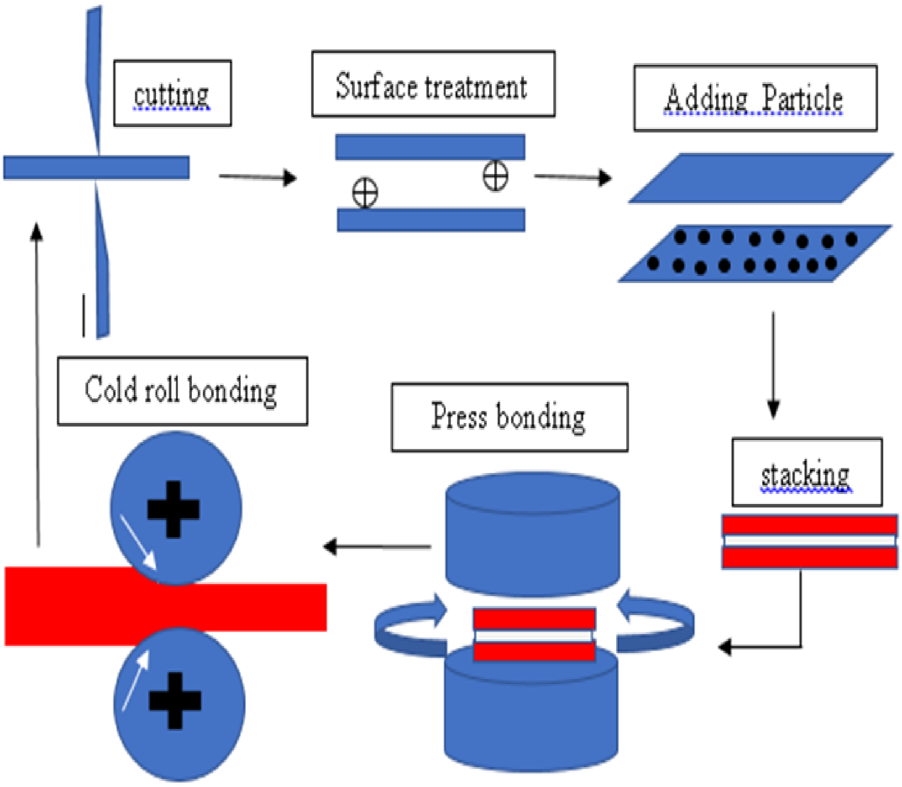

Fig. 1. Schematic of Repetitive Press-Roll Forming (RPRF) Process.

RESULT AND DISCUSSION

Density and porosity of the composite

Density testing aims to determine the density of aluminum Based Composites (AA1100) produced. Density will affect the mass of an object by reducing size and weight. The results of this study are expected to produce composites that have high mechanical properties, low weight, and low cost, and have excellent performance optimization.

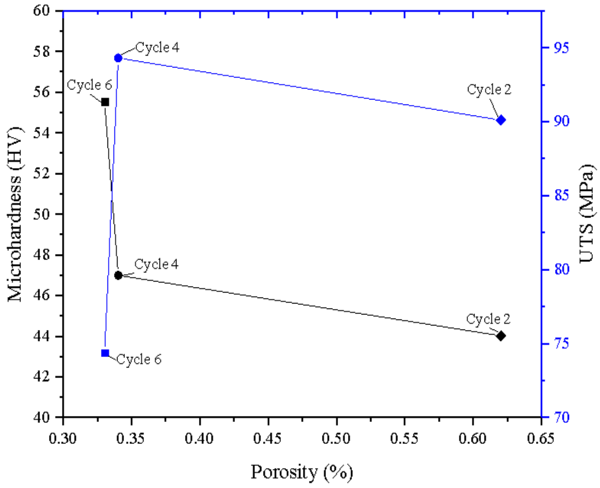

Fig. 2. Percent Porosity of the Mechanical Properties of AA1100 by RPRF Process.

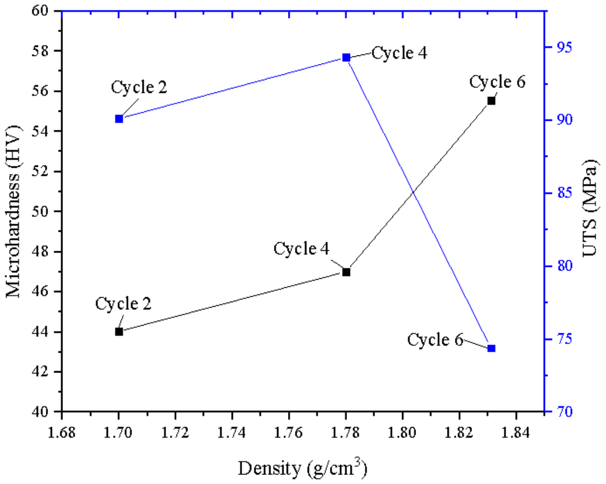

Fig. 3. Density of Mechanical Properties of AA1100 by RPRF Process.

Density test uses the Archimedes principle based on the ASTM D792 standard, while porosity uses the ASTM C20 standard. The results of testing density and porosity by adding SiC particles and the number of rolling cycles on aluminum can reduce % porosity. Porosity test results show that the MX6 AA1100/SiC sample has the lowest % porosity value of 0.33%. The lower the porosity value, the hardness of a material will increase.

Development of the microstructures

The micro structures formed in the cold working process is a strain hardening mechanism which results in deformation by a shift or movement of atoms in a crystal called a dislocation. In two cycles rolling the interface distance is still uneven because SiC particles are not uniform, because the pressure applied to the compression process is not optimal, the bond between SiC and aluminum matrix does not bound perfectly. After four cycles, the dislocation density increases, however, the density in the sub grains decreases, will be becomes finer when porosity decreases due to the diffused SiC particles covering the porosity.

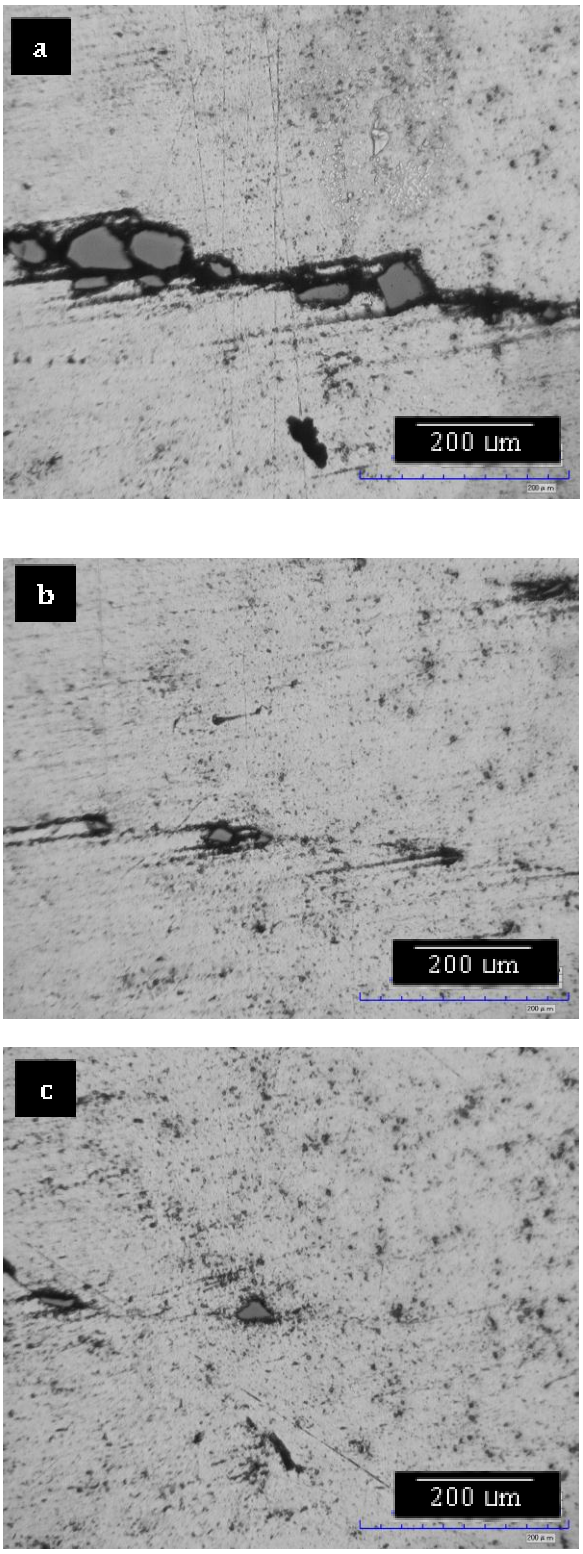

Fig. 4. Interface bonding of Al-based composites by RPRF process after (a) 2 cycles (b) 4 cycles and (c) 6 cycles

Cycle 6 shows that the distribution of the particle reinforcement is almost complete into the matrix, with the loss of the interface on the aluminum matrix and the small particle size of SiC with particle distribution dispersed throughout the aluminum matrix so that covering porosity is due to the presence of a SiC reinforcement layer which can hinder strains from the surface into the Al matrix (Zheng Lv, 2016). With the increasing number of roll cycles, SiC particles are dispersed from the interface to most aluminum layers and all discontinuities in the interface disappear so that SiC cover porosity (Alizadeh, M and Paydar, M, H, 2010).

In addition to the number of rolling cycles that affect the distribution of SiC particles in the aluminum matrix, the direction of SiC preparation particle can also affect the SiC distribution and the quality of the bonding interface. The direction of SiC reinforce using the mix direction, SiC particles are arranged vertically and horizontally when the RPRF process is carried out. The distribution of dispersed particles in the aluminum matrix is evenly distributed across the aluminum matrix side compared to the direction of transversion and cross section.

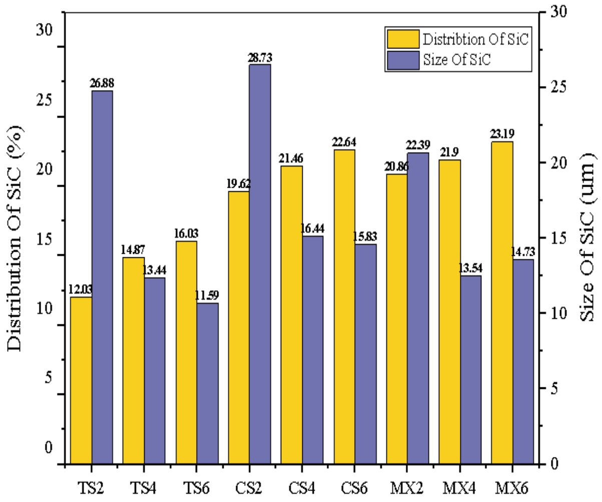

Fig. 5. Graph the SiC distribution value and SiC size by the number of cycles and the direction of SiC result of the RPRF process

By increasing roll cycle, the thickness of the interface layer and SiC particle size decreases, data for each cycle with interface thickness of two cycles was 15,977 µm, four cycle was 13.701 µm and the cycle of 10,086 µm as a result SiC particles spread over most aluminum matrix. These results indicate that the dispersion of SiC particles in the aluminum matrix becomes more uniform by increasing the number of cycles, gradually. The presence of SiC particles in the aluminum matrix increases the density of dislocations. Repeated rolling cycle can result in more tightly bonded interface until there is a missing line. ARB process with a reduction of 50% reduction causing most of the porosity disappears, the presence of shifting field of particle is a sign of interface bonding to imperfect material (Pramono. A, 2015).

Mechanical properties of the composites

Tabel. 2. Mechanical properties of AA1100 based composites

Materials	Vickers Hardness HV10	Tensile Strength MPa	Elongation %
TS2	43,23	89,87	15,84
TS4	45,56	57,79	9,98
TS6	49,67	81,42	8,79
CS2	43, 67	94,24	14,26
CS4	45,60	95,52	16,80
CS6	51,56	90,46	4,91
MX2	44,06	90,13	16,16
MX4	47,01	94,33	4,36
MX6	55,54	74,41	8,43

Table 2. Shows the hardness value of AA1100/SiC after the RPRF process increases significantly with the variables and variations added. These results indicate that the number of roll cycles and the direction of compilation of SiC affect the hardness value of AA 1100 in the RPRF process. Variations with the direction of sic mix particles in the matrix obtain a higher hardness value. Hardness value before the RPRF process was 26 HV after second cycle the hardness was 44,06 HV, fourth cycles hardness was 47,01 HV and then sixth cycles hardness is 55,54 HV.

The hardness test results on Aluminum alloy 1100 with the influence of the rolling cycle and the direction of SiC with a process temperature of 350 ^{0}C and SiC weight percent of 0.4% showed that strain hardening in the hardness RPRF process cycle increased after the initial rolling process until the next cycle, after each more cycle, hardness value in the RPRF process increase respectively.

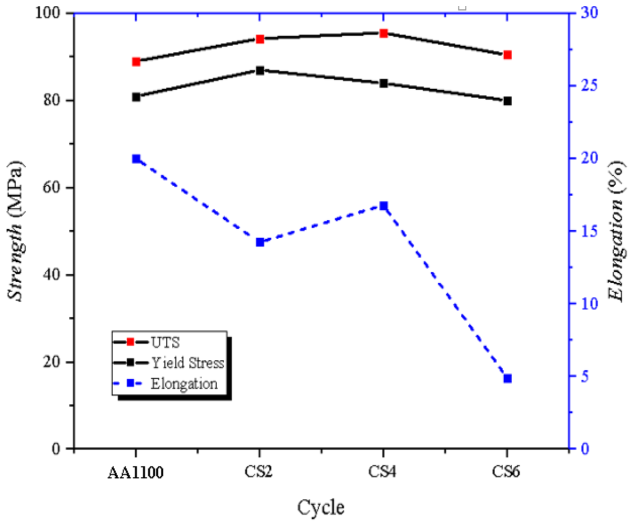

Fig. 6. Mechanical properties of the Al/SiC composites produced by the RPRF process in various cycles

In table 2. the sample of AA1100/SiC the highest UTS value was obtained by sample AA1100/SiC with variations in the direction of SiC particles in a Cross Section. In the number of 2 rolling cycles, it has a ultimate tensile strength (UTS) of 94.24 MPa, percent elongation is 14.276%. The yield stress is 87 MPa, the number of 4 rolling cycles becomes the tensile strength (UTS) value of 95.52 MPa, the percent elongation is 16.80%. The stress yield value is 84 MPa. and the rolling 6 cycles of UTS was 90.46 with percent elongation of 4.91%, yield stress value was 80 MPa.

The increase tensile strength can be associated with strain hardening due to repeated plastic deformation and the addition of a larger SiC, and with higher dislocation density and sub grain formation (S.O. Gashti, 2015). Figure 6. Shown tensile strength increases with increasing cycles, but the last cycle has a smaller value. After 6 roll cycles, UTS and elongation decrease which means that the material has increased dislocation density so that the tensile strength decreases as well as increased stress. The decreasing elongation values can be associated with intensive strain hardening which occurs through a rolling variation process, causing a decrease in mobility of dislocations during tensile testing. The decrease with increasing number of roll cycles shows that the ability of the results obtained in the evolution of mechanical properties with typical behavior of materials with fine grain structure (Ana Alil, 2014).

CONCLUSIOUNS

The goal of RPRF methods is reduce of number cycles on processes that will be explored. By addition of SiC particle ceramics at AA1100 it can improve the material properties where SiC particles attached to the interface and dispersion in the aluminum matrix reduce porosity and delamination produced by the RPRF process. Increasing of roll cycles was used on the RPRF process, the thickness of interface layer formed will decrease, the presence of missing lines increases the material's mechanical properties. Using the mix direction of SiC particles can distribute more evenly distributed SiC particles produced by the RPRF process.

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