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Cite as: AIP Conference Proceedings **2213**, 020210 (2020); https://doi.org/10.1063/5.0000245
Published Online: 25 March 2020

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Numerical Analysis Techniques and Model Development with SEM Evaluation to Improve the Formability of Aluminium Matrix Composite

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Abstract. Nowadays; aluminium and aluminium alloys are consider the most popular and widely used as metal matrix composites (MMC) due to their attractive properties like, light weight, low density, high damping capacity high thermal and electrical conductivity and their capability to be strengthened by precipitation. In forming process of aluminium matrix composites (AMCs), the problems of high friction and cracks during the process with high heat generation due to particles dislocation which leads to high stress generation and micro cracks which finally cause products faller need to be solved. The main objectives of this current research are to find out the main influencing factors on the formability and product quality of (AMCs) through developing a suitable model and numerical analysis. For this purposes, the commercial software (ABAQUS/CAE) has been adopted as a finite element analysis for simulation the formality behaviour of aluminium matrix composite (LM6/TiC). Experimentally, the (SEM) micrograph test was deployed to find some specific proofs and evidences on the reinforcement particles distribution and orientation with the main matrix and the bonding strength between them. As well as, it easy to analyse the composite fracture surface by (SEM) to show the reacted interfaces details. Simulation results show that the weak regions in forming of this matrix composite are those that initially affected in the starting of forming process where the particles dislocation and matrix deformations are maximum. This will leads to high values of temperature generation and stress concentrations in and around the sharp edges and semi- rounded reigns which leads to deficiency of the process and minimize the product quality. Moreover, the micrographs of (SEM) test results was revealed that the dislocations development in aluminium alloys microstructures will results in formation a new grain size with better mechanical properties. It's concluded that, the composite aluminium to be formed should be heated to elevated temperature less than melting point before forming process in order to get better surface finish.

INTRODUCTION

Metal Matrix Composite (MMC) are basically concentrate to motivate some mechanical properties like tensile, strength, and hardness. Aluminium matrix (AMs) which reinforced with Titanium carbides (TiC) are widely used in many industrial applications such as automobile and aerospace based on their superior advantages [1].

Reinforcements materials can classified in to different types and groups. It can be found as particulate, monofilament, whisker and short fiber, continuous fiber, woven and hybrid reinforced composites. Particulate reinforcements are normally carbides or borides or oxides (SiC, TiB2 or Al2O3). The others types of reinforcements are available in different shape with different volume of fraction. The hybrid reenrolment is consisting of more than one type or mix from them [2]. The presents of some elements like silica with reinforcement particles like fly ash in aluminium matrix may cause increases in hardness and brittleness of aluminium composites [3].

Titanium carbide (TiC) particulates reinforcement used with aluminium matrix as (Al-TiC) provide excellent mixture with better mechanical properties like resistance at elevated temperatures, stiffness, specific strength, creep

2nd International Conference on Materials Engineering & Science (IConMEAS 2019)
AIP Conf. Proc. 2213, 020210-1–020210-10; https://doi.org/10.1063/5.0000245
Published by AIP Publishing. 978-0-7354-1964-3/$30.00

and fatigue. The (TiC) particulates are providing strong consolidation to the aluminium base matrix through formulation new texture. Moreover, the high ratio of weigh to the shear stiffness will offers good optimization for the structure geometry [4].

Sheet metals can form by using many traditional forming techniques. During forming process of aluminium matrix composite (Al-TiC), the composite grain size will be refined due to recrystallization and shear strain superposition. As well as, microstructure test show that, the randomly distributions of grain size result in various microstructure configurations [5].

The main properties of aluminium (Al-TiC) MMC are depends on distribution and orientation of particles, fraction volume, particles size and fabrication method. The complex structure of the reinforcement particulates in matrix composites makes some difficulty in production of the parameters that effects on their properties, and for these reasons the demands was increased for analysis and simulation their characteristics [6].

The behaviour of yielding can investigate by using finite elements analysis. Draw bending process can simulate by using F.E.M through conducting with composite element model.

Virtual experiments are usually advised to identify the nature of deformation and the surface yield profile, and it's always used to motivate the findings with clear vision to expand the possibilities of solution [7, 8].
Analytical solution based on F.E.M is usually used to model the behaviour of formed aluminium sheet metal under different conditions of bending and compression. The results of modelling will used to find better calibration in order to improve the experimental findings [9, 10]. Understanding of the microstructure characterization of metal matrix composite is necessary in forecasting their behaviour under different working conditions. Since composite forming, there many failler mode can consider like matrix shearing, matrix buckling and breakage. the failure index is more complex due to nonlinear shear behavior and combination of shear stress and transverse compressive stress [11, 12].

MARTIAL PROPERTIES AND TOOLS DESIGN LAYOUT

The aluminum matrix composite used in this research was a rectangular plate with the dimensions (150 * 90) mm and (1) mm thickness. After forming process, the product dimensions will be as in "Fig. 1" below.

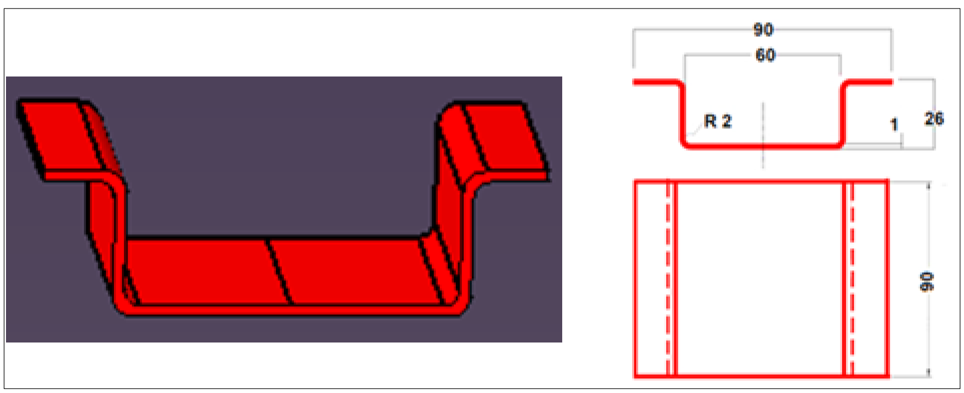

FIGURE 1. Final product after forming.

The composite material used in this research was (LM6 + Titanium Carbide TiC). The weight percentage of (TiC) was (2) % as a volume fraction (Vf). The chemical composition of (LM6) and the mechanical properties of (TiC) are listed in TABLE 1. and TABLE 2. **Below.**

TABLE 1. Chemical composition of LM6.

Elements	Composition (%)
Al	86
Mg	0.1
Cu	0.1
Si	12
Fe	0.6
Mn	0.45
Lead	0.1

TABLE 1. Continued.

Elements	**Composition (%)**
Ni	0.1
Zn	0.1
Tin	0.05
Titanium	0.2
Other Elements	0.2

TABLE 2. Mechanical properties of (TiC).

Property	**Value**
Density, gm/cc	86
Thermal conductivity at 298K, W/m.K	33
Heat capacity Cp at 298K , (J/mol. K)	33-34
Space group	Fm3m
Thermal expansion coefficient, (at 300-1400K), grad-1	7.0-7.9
Young Modulus, GPa	460-494
Hardness Hv, GPa	30

To illustrate and determine the forming mechanism, and the material behaviour during the process; design of the forming tools should be established. This design will explain all forming steps including product ejecting. The first stage including cantering the composite blank metal on the blank holder as shown in "Fig. 2"

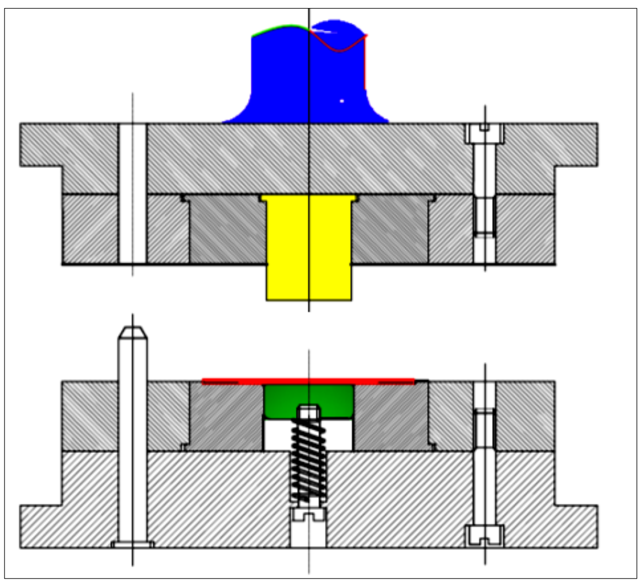

FIGURE 2. First stage of the process.

In the second stage; the press will push the punch downward to form the composite plate to the desired shape as shown in "Fig. 3".

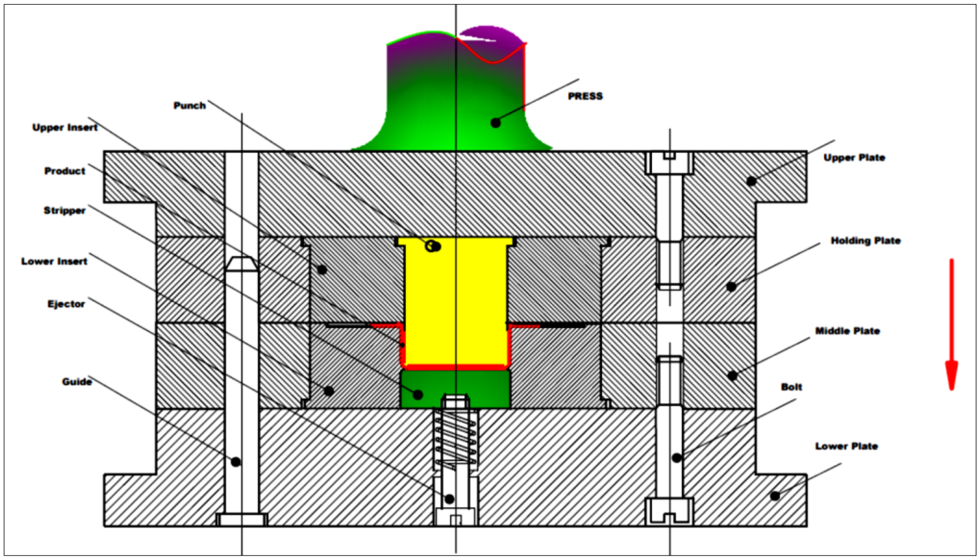

FIGURE 3. Second stage of bending process.

Ejection the product out of the die will be the final stage as shown in “Fig. 4”.

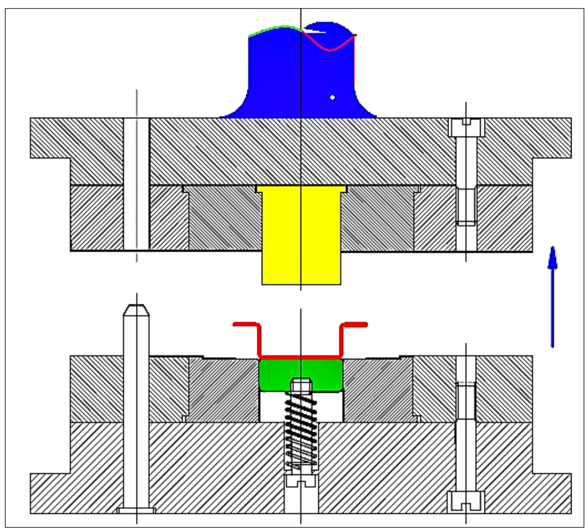
FIGURE 4. Final stage is ejection the product.

Modelling and Simulation Process

Modelling each part individually and all parts together as assembly is very important to avoid non- desirable interaction between the parts during simulation and to ensure there’s no conflict between all parts during assembly. “Figure 5” illustrate (3D) virtual model for the final forming step.

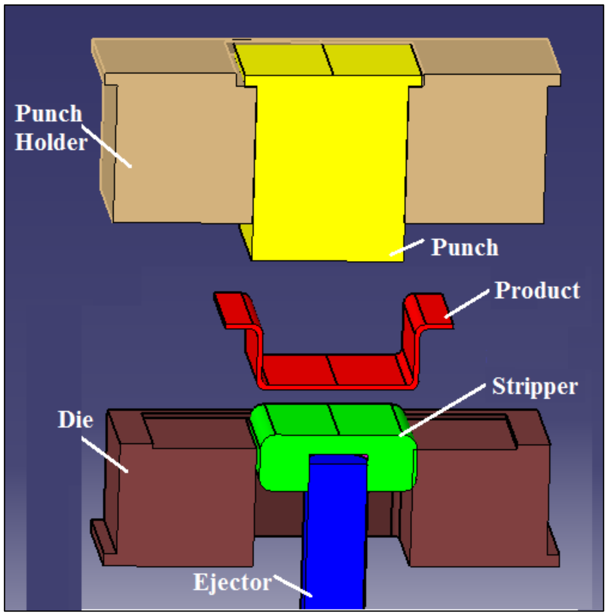

FIGURE 5. (3D) model for the final forming step.

To simulate the behaviour of the composite material during forming process; the elastic properties will consider linearly dependent on some parameters like, the shear value before failure, matrix properties and the matrix failure index. During the contact and interaction between the surfaces; the contact parts will classify as a deformable parts and rigid parts depending on the material properties as well as the behaviour of deformation.

The criteria used in many finite element methods, and in (ABAQUS) are used to define the rigid body as a MASTER, and the deformable body as SLAVE. Therefore, the composite plate will define as slave, and the punch with die is considered as master. At the initial analysis step, the punch will move down to be in touch with the upper surface of the plate by using the option (SURFACE TO SURFACE CONTACT) as shown in “Fig. 6”.

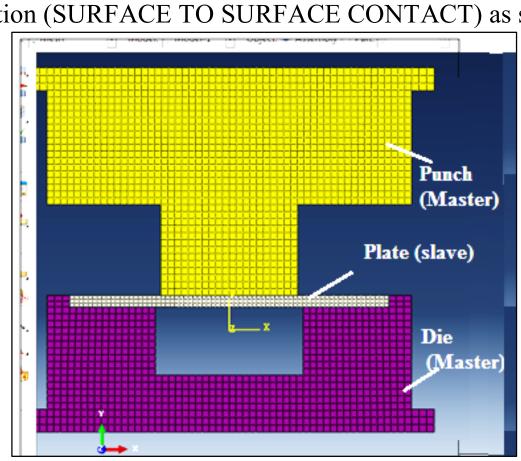

FIGURE 6. Contact behaviour between the parts.

Furthermore; there are some important boundary conditions should be define to control the displacement, velocity and degree of freedom. In the first analysis step, the die will be constrain to prevent form any movement in all direction, Moreover, pressure load will apply on the upper side to make the punch to move downward and push the plate inside the die, as shown in “Fig. 7”.

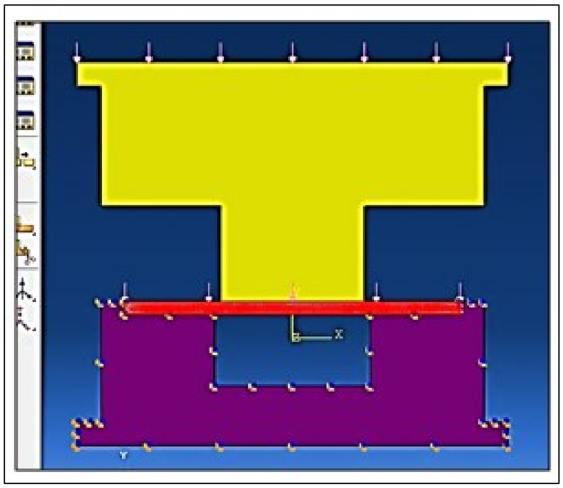

FIGURE 7. Boundary condition and applying load.

The pressure load was applied on the length direction of the plate, and any faller will highly depend on direction, material orientation and geometry.

Defult algorithim with mapped tri-meshing on boundry faces are used as a mesh control option for meshing the master parts, while orphane mesh are used to mesh the composite plat, as shown in “Fig. 8”.

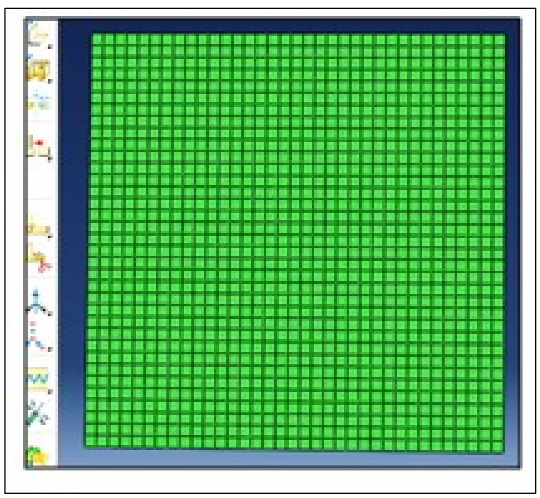

FIGURE 8. Composite plate in orphan mesh.

This finite element model is consisting of plane stress elements (CPS4), and the implementation of material behavior with this type elment will depend on the starting time of increment to ensure that this time is small and sufficient. To ensure high simulation accuracy, the increment time should be small and effectively used.

RESULTS AND DISCUSSION

The important part in this research is to estimate and determine the best method that offering high weight ratio to shear stiffness through modelling and simulation, and then estimate the plastic behaviour of the formed sheet metal. Through this virtual experiment its possible to offers an effective imagination on the behaviour and response of aluminium composite material during forming process. However, the longitudinal strain of this materail is expected to reach maximum value at the final forming step due to sever dislocation in particles bonding as shown in the contour of plastic strain in “Fig. 9”.

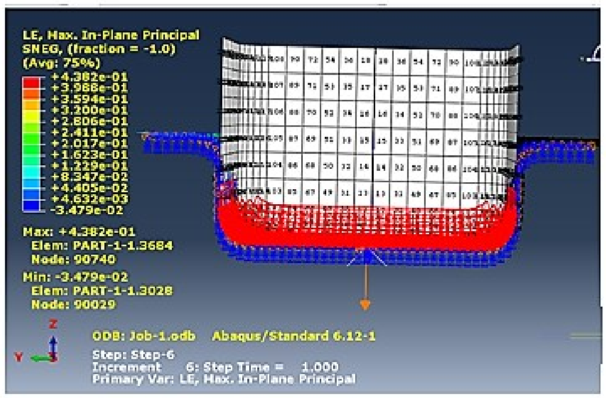

FIGURE 9. Contour of plastic strain.

In this analysis, and during the punch load transfer, its found that the composite behavior are strongly depends finite element mesh refinement, whereas, more refinement will needs to apply more forces, asshown in "Fig. 10".

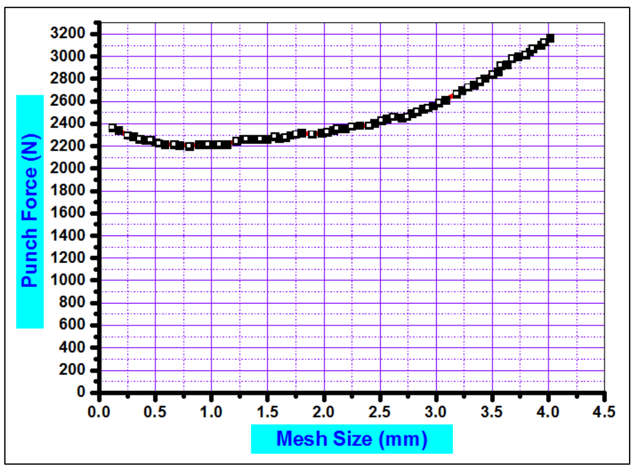

FIGURE 10. Relationship between mesh refinement and applied force.

Moreover; during the punch travelling downward to form the sheet metal, the material strength will increase epically at the die entrance zone, and the misses stresses will reach the maximum values at the end of final forming step (step 6). Contour of Von Mises stresses is shown in "Fig. 11".

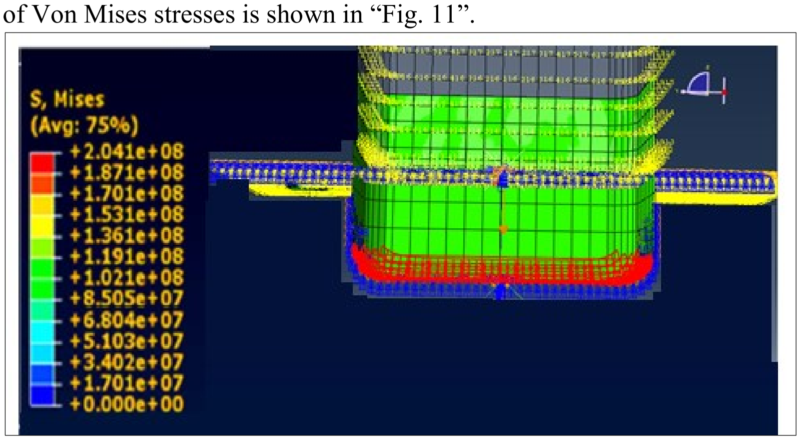

FIGURE 11. Contour of Von- Mises stresses.

Hence; the relation between the Von- Mises stresses with strain hardining at the end of the previous step as a comparison between matrix and composite are shown in "Fig. 12".below.

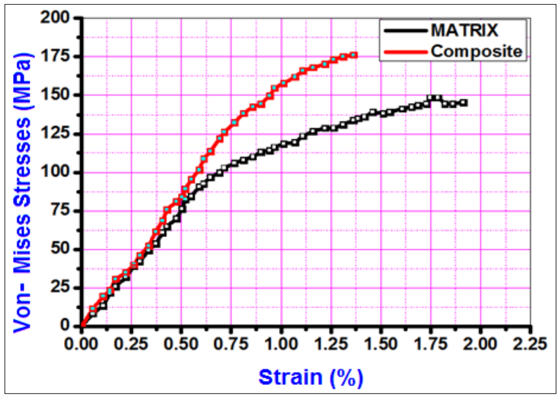

FIGURE 12. Contour of Von- Mises stresses.

Due to the nature and direction of forming process, all materail elements will forced to move downward and the speed of particles is rapidly increas to reach the maximum value at the node number (90026) when composite metal rest on the last surface of the die as show in contour plot of resultant velocity in “Fig. 13”.

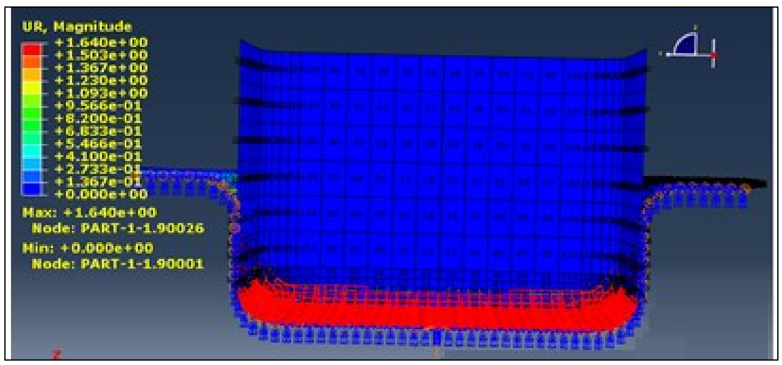

FIGURE 13. Contour plot of resultant velocity.

The content of titanium carbides (TiC) particles as a reinforced material is about (1.8) %wt was added to the main matrix. The results of mechanical tests and measurements like microhardness and tensile test confirm a lot of improvement in mechanical properties as shown in “Fig. 14”.

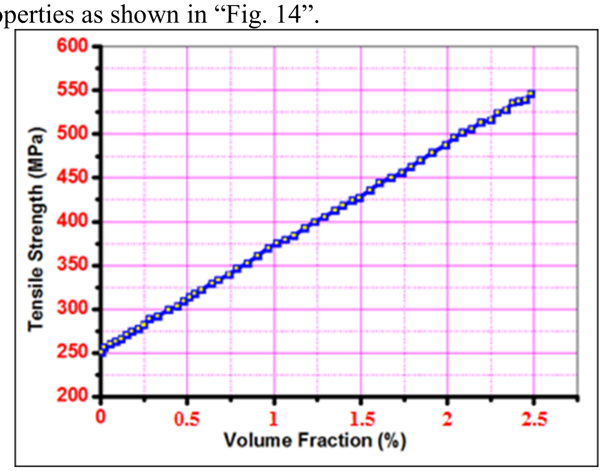

FIGURE 14. Contour plot of resultant velocity.

As a comparison between aluminum composite, and pure aluminum in terms of strees – strain relationship, its found that this relation will be as in “Fig. 15”.

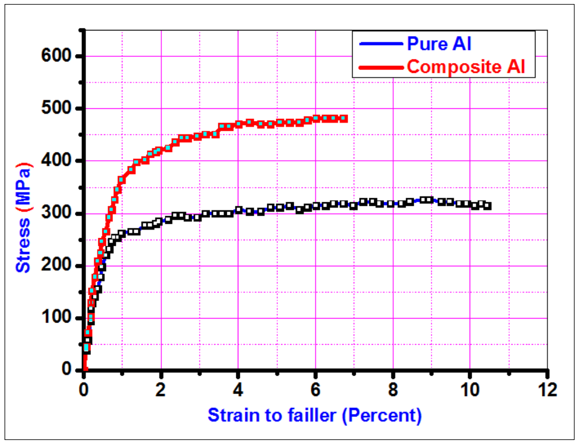

FIGURE 15. Comparison between pure and aluminum composite in Strees – strain.

Microstructure Evaluation

The micrographs of scanning electron microscopy (SEM) used to evaluate the reinforcement texture properties after and before forming process This test (SEM) was accomplished by using the variable pressure (Hitachi S-3000N).

Samples have been selected from different zones of composite billet before and after forming. High surface treatments were accomplished in preparing the samples for SEM test including cleaning by chemical solvents, etching and polishing.

Results of test revealed that a new crystallization was formed and the density, orientations with a new formation was appeared. Figure (16) A and B illustrate the microstructure of the composite material before and after forming respectively, where the (TiC) was representative by white particles, and the others for matrix.

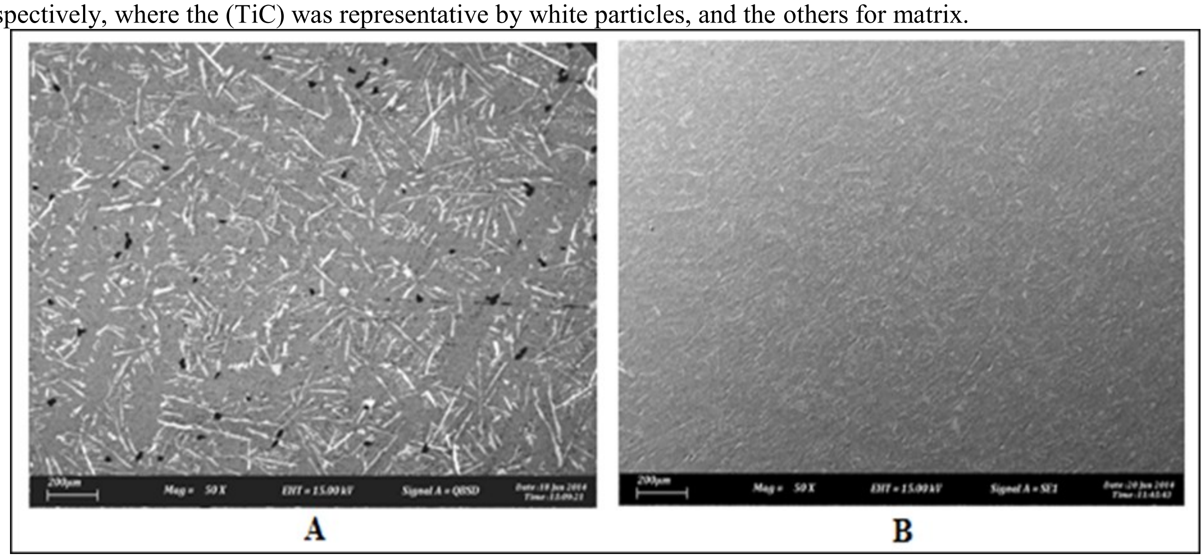

FIGURE 16. Microstructure of composite. A before forming. B after forming.

Many changes were happened during extrusion on the microstructures, resulting in a new distribution of the orientations and grain. The dislocations development in microstructures of the matrix results from stacking between composite and tools with high temperatures due to friction.

CONCLUSIONS

Some conclusions have been summarized as in below:-

1- During forming the composite, the particular orientation will be change, also the inclusion density will extensive, and this will improve and enhance the physical properties
2- Simulation results are highly sensitive to the element and mesh type, and this demonstrated clearly when change the element type from full integration type to reduced integration type.
3- The behaviour of AMMC is normally correlated with microstructure configurations of the basic matrix alloy.
4- When volume fraction of the reinforcement material is more than the critical amount, the reinforcement will ensure stiffness and strength at specific applied load.

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