Arch. Metall. Mater. **70** (2025), 1, 183-192

DOI: https://doi.org/10.24425/amm.2025.152532

B. VISWANADHAPALLI[1], V.K. BUPESH RAJA[1*], K. CHAITANYA[2], S. KANNAN[3]

FORMABILITY STUDIES ON MAGNESIUM BASED AZ31B ALLOY SHEET IN LS DYNA PROGRAM CODE

Magnesium alloys has potential applications in aerospace and automotive industries as they are having good formability. Material properties like yield strength, ductility, have direct influence on material's formability and product quality. At high temperature applications like aeroengine and steam engine, finding these properties are very crucial. For this purpose, uni-axial tension tests are performed at high temperatures on AZ31B magnesium alloy sheet to evaluate material formability properties. Finite element-based simulations have also been carried in LS Dyna program code. The output of the simulation is to find effective stresses and effective plastic strains. For this purpose, Tresca and Von Mises yielding conditions are utilized. These stresses are crucial in predicting and evaluating the forming limits of the material before necking. The results obtained from simulation code are consistent with experimental observations. An attempt has been made to predict formability by machine learning models. Random Forest shows the better model in predicting the formability. It has been concluded that the machine learning and Dyna code predictions has greatly minimises the physical experimentation.

Keywords: Magnesium alloy sheet; uni-axial tension test; LS Dyna program code; machine learning model

1. Introduction

Magnesium alloys are good in formability and light in weight. These properties are very attractive to the aerospace and automotive industries today. Additional features like rich availability in the earth's crust, emission-free, good machinability, and weldability, recyclability, etc., are added advantages of the magnesium alloys. The lightness of magnesium alloys results in fuel economy, a demanding feature in the aircraft and automotive industries. Other companies, laptop and smartphone makers are also looking for lightweight materials with just the right amount of strength. The good formability of magnesium alloys at high temperatures makes them suitable for the manufacture of many complex automotive and aircraft engine parts [1]. Magnesium welding has gained momentum and magnesium alloys have been used in large quantities in the automobile industry. High temperature tensile tests are performed on magnesium AZ31B alloy sheet to measure material formability in terms of elongation, yield strength, etc. The literature on machine learning models, to predict the formability of magnesium, is not sufficiently registered. Present work is thus concerned with the investigation of the same and built four different machine learning models.

2. Materials and methods

Forming basically changing the shape and size of a solid preform raw material such as ingots, billets, plates, slabs, and sheets by plastic deformation. Bulk forming methods such as rolling, forging, extrusion, drawing, sheet forming methods such as cup drawing, blanking, punching, etc. are used for this forming. Magnesium based AZ31B alloy sheet is employed in this work, to perform uniaxial stretching, which is commonly used sheet metal forming operation [2].

2.1. Uni axial stretching – working modes

Tension test, a very common mechanical test which take a test piece and stretches it along its length [3]. It is a uniaxial test, meaning that it applies a load in one direction only [4]. During the test, the test machine measures the applied load, and change in length of the test piece. The main output from the tensile test is the stress-strain curve, which describes the material's mechanical behaviour. When metals deform plastically at temperatures below their recrystallization temperatures, they are said to be cold

1 SCHOOL OF MECHANICAL ENGINEERING, SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY, CHENNAI INDIA
2 DEPARTMENT OF COMPUTER SCIENCE ENGINEERING, GOKARAJU RANGARAJU INSTITUTE OF ENGINEERING AND TECHNOLOGY, HYDERABAD INDIA
3 DEAN – ENGINEERING, ARCHITECTURE AND INTERIOR DESIGN AMITY UNIVERSITY, DUBAI, UAE

* Corresponding author: bupesh.v.k@gmail.com

worked. At this recrystallisation temperature the deformed and strained grains become strain free, equiaxed or spherical. In cold working strain hardening takes place but in hot working grain refinement happens. Because of this fact, cold worked products exhibit good strength, hardness but poor ductility. Ductility is a prime parameter that influence material's formability, ability to form into desired shape [5]. Good quality formed components are having huge demand in aero and automotive industries. To improve ductility, it is preferable to plastically deform the material above recrystallization temperature at the expense of strength and hardness. To achieve good plastic deformation, the requirements are less load and high amount of ductility. For this purpose, temperature of work piece before any forming method must be raised. Ductility plays vital role in material formability and measured commonly in percent elongation [6]. Magnesium AZ31B alloy possess moderate strength and poor ductility at room temperature. Hence high temperature tension tests are important to predict the material properties like stresses and strains, and ductility, in such high temperature applications. Tensile tests are mainly performed to determine the effect of strain on strength. Torsion, compression, and bulge tests are sometimes used, but a tensile test is simpler and more commonly used.

2.2. Experimentation

High temperature tensile tests are performed on AZ31B magnesium alloy sheet of 2 mm thickness to evaluate the strength of materials for high temperature applications. For this purpose, dog bone specimens are prepared from commercial sheet metal of 600×900 mm. A total of 36 different experiments are conducted, by taking four different test temperatures (24, 200, 250 and 300°C) and three strain rates (0.1, 0.01 and 0.001 mm/s).

Schematic of uni-axial tensile stretching using hot forming machine is shown in Fig. 1.

Generally, in a tensile test, the stain rate is in the range of 10^{-1}/sec to 10^{-3}/sec, and the temperature is in between 18 and 250°C. Temperature and stress rate influence the test results [7].

Tensile specimens are prepared in subsize ASTM-E8 using a wire-cut EDM process along three directions with respect to the manufacturing or rolling directions (RD), as shown in Fig. 2.

After measuring specimen dimensions and marking gauge length, then pin the specimen into the fixing dies which will be used to attach the specimen to the tensile machine. Thermocouples are then connected to the specimen to allow the temperature and temperature gradient to be monitored during the test. The specimen has now been loaded into the tensile frame and using computer-controlled furnace heated up to the specified temperature. Ceramic wool is used in the hot furnace to prevent the heat losses.

Soaking time of 10-20 minutes allowed before applying load. A slight pre-load is applied about 1 kN. The load and strain are recorded by the computer data acquisition system as the load is increased until the specimen yields or breaks. Once the specimen breaks the furnace is opened and the specimen is removed and allowed to cool. The specimen is then measured for thickness to calculate reduction of area, and for gauge length to calculate the elongation. The ultimate or highest load is recorded and the load at yield are divided by the original cross-sectional area to calculate stresses. Experimental plan and percent elongation values calculated by the computer DAQ system, listed in the TABLE 1.

Fig. 1. Schematic of Hot Tensile equipment

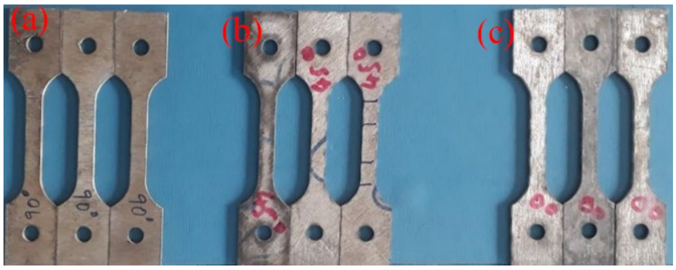


Fig. 2. Specimen coupons

Percent elongation, which is a measurement of the amount a material will plastically and elastically deform up to fracture [8]. Compare the final length of the material with the original length to determine elongation and ductility of the material.

The higher the ductility, the higher the formability [9]. Care must be taken to input sheet cross section and gauge length before starting the experiment to get the accurate results. Other data like time, load, engineering stress-strain values, can be obtained from the computer software. However, true stress-strain values are generally given as input to the dyna code. Origin-pro software is used to analyse big experimental data and create true stress-strain curves shown in Fig. 3 and Fig. 4.

TABLE 1

Experimental results of elongation values in percentage under different test conditions

No. of Experi-ments	Grain orientation	Strain Rate, mm/s	Elongation, %			
			24°C	200°C	250°C	300°C
1-4	Along RD	0.1/s	16	20.2	26	30
5-8	Along RD	0.01/s	22	32	22	24
9-12	Along RD	0.001/s	24	21.2	26	22
13-16	45° to RD	0.1/s	11.2	18.6	34	24
17-20	45° to RD	0.01/s	11.6	31	30	20
21-24	45° to RD	0.001/s	14.8	28	18	18
25-28	90° to RD	0.1/s	12.4	17.6	28	30
29-32	90° to RD	0.01/s	13.6	27.2	22	24
33-36	90° to RD	0.001/s	12	28.4	22	20

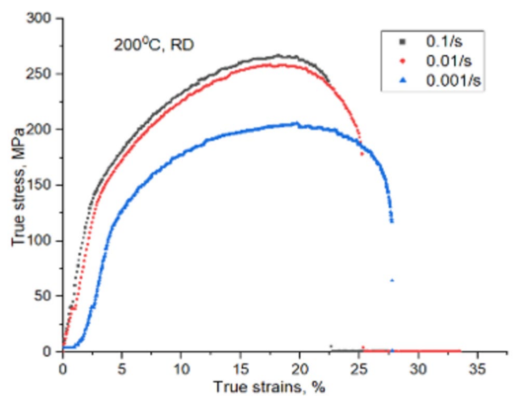


Fig. 3. (a) True stress-strain curve

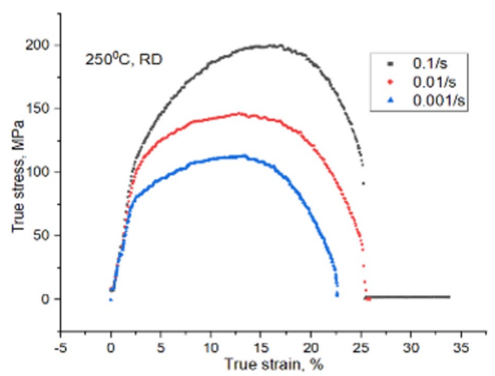


Fig. 3. (b) Trues tress-strain curve

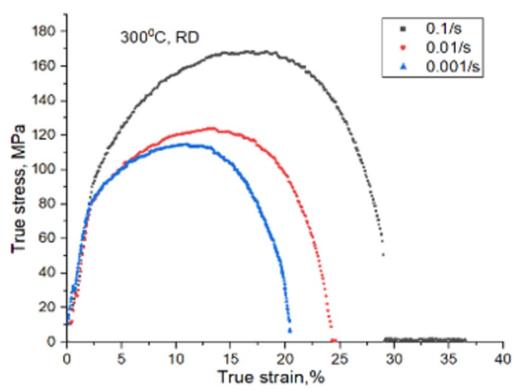


Fig. 3. (c) True stress-strain curve

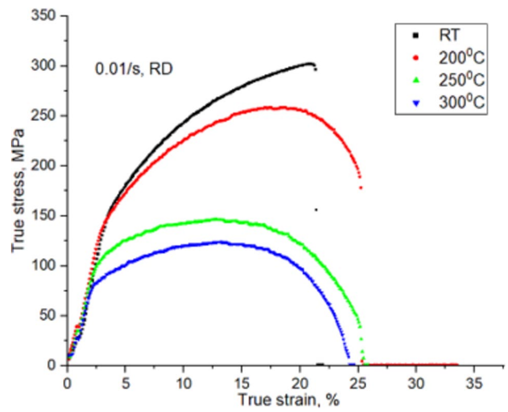


Fig. 4. (a) True stress-strain curve

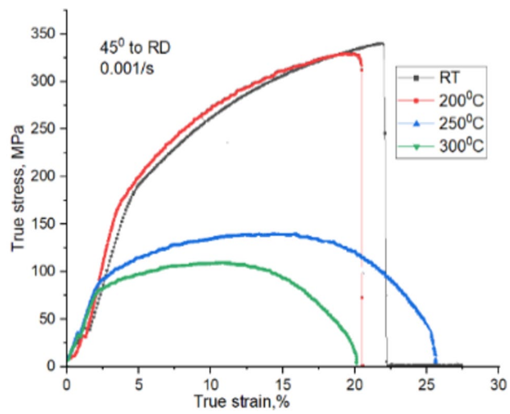


Fig. 4. (b) True stress-strain curve

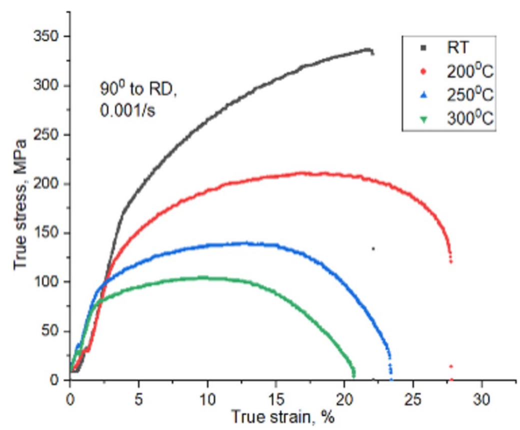


Fig. 4. (c) True stress-strain curve

2.3. High temperature applications

Elevated temperature meaning operating temperatures more than half the melting temperature of the material. At these temperatures, properties like creep resistance, and stable micro-structure, oxidation, and corrosion resistance etc., are considered as most important attributes. Other properties like density, modulus etc. are important as in case of aircraft and reliability of many years as needed in case of ground-based applications like power plants, road transport. Thus, it's important to focus on the mechanical properties of high strength materials at elevated temperatures. Here the three laws of thermodynamics apply. Energy conservation, attaining high temperatures, and it is not possible to attain absolute zero temperature. If achieved 10% improvement in the system efficiency then it's possible to achieve in one stroke all the requirements of legal agreements, for example, CO_2 Emissions. This was the big area of developments and research concern in present day scenario.

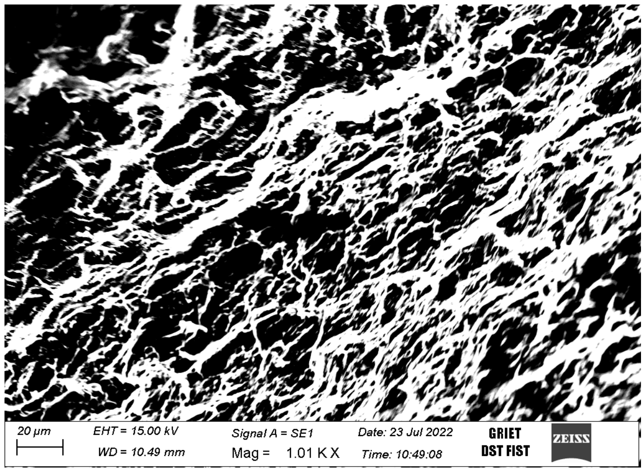
Operating conditions of aeroengine and power plant turbine listed in the TABLE 2. The components need to withstand such huge temperatures and low pressures as in aero engine. Parts are subjected to high temperatures and pressures as well as in power plant. Though the pressures 10 MPa and 100 MPa are seemed to be low, but at high temperatures these pressures produce very high stresses. Most of the turbine blades that go into the jet engine which are in the hot region of the engine has coatings. No coatings are applied as the steam engine components are relatively larger. Gas engine turbine blades use forced cooling through the channels inside the blades, though it reduces efficiency. These operating conditions are different and demand different kinds of metallurgical and engineering technologies. Aero engine parts are designed for a life order of 10^4 hrs. or close to one year, but the parts of a stream power plant designed in such a that they could sustain at least for a period of 25-30 years. For example, improving strength of power plant pipes by inventing newer materials is good, but reduction of their weight pipes and their huge support structure is also important, because stresses associated with these huge structural weights are very large. There are lot big advantages to making stronger and lighter materials which can survive at higher temperatures. AZ31B magnesium alloy, for example, is both the strong and light in weight. Hot tensile test investigates the few mechanical properties that are essential in such high temperature working conditions. Investigation of stable lattice structure, creep and yield strength and ultimate tensile strength, and elongation are the outcomes of the experiment. Simulated data are in good agreement with the experimental results.

TABLE 2

Operating conditions of aeroengine and power plant turbine

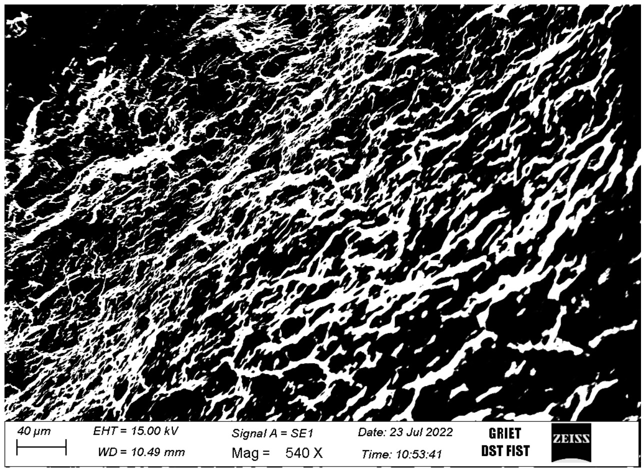
Property	Gas Turbine	Steam turbine
Temperature	>10000C	600-7000C
Pressure	3-4 bar	350-400 bar
Design life	1-2 years	20-30 years
Stresses	10 MPa	100 MPa
Coating	Yes	No
Forced cooling	Yes	No
Single crystal	Yes	No

An attempt has been made to perform fracture analysis on four broken specimens tested at room temperature to 300°C to predict whether the failure associated with ductile or brittle. Fractographs of the experimental alloy tested at room temperature and elevated temperature are shown in Figs. 5-8.



(a) RT01 (b) RT04

Fig. 5. Fractographs of specimen tested at room temperature



(a) 20001 (b) 20002

Fig. 6. Fractographs of specimen tested at 200 deg C

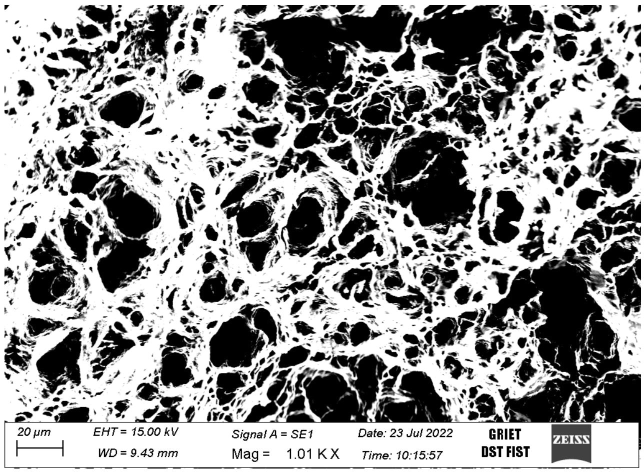


Fig. 7. (a) 25001

Interestingly, the fractograph of the alloy tested at room temperature exhibits elongated dimples, which may be the residue signature of the as – received hot rolled material having elongated grains.

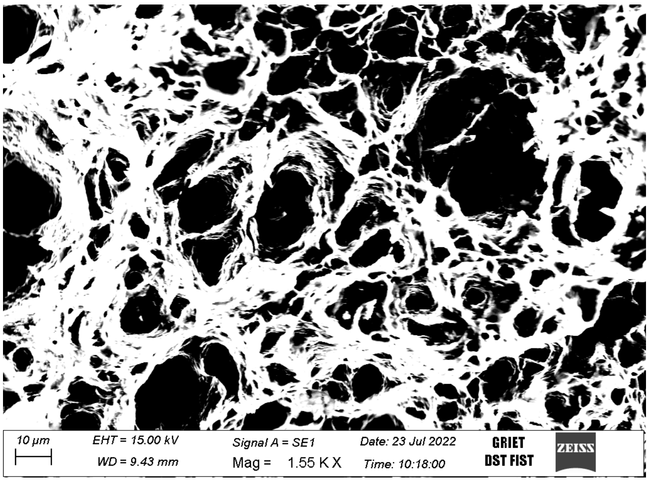


Fig. 7. (b) 25002

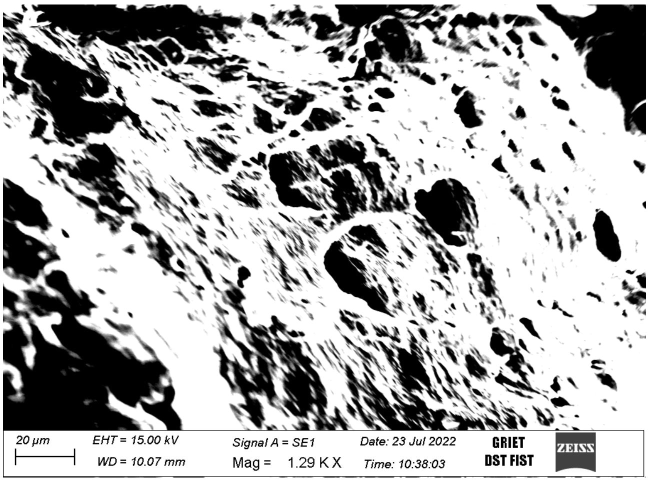


Fig. 8. (a) 30002

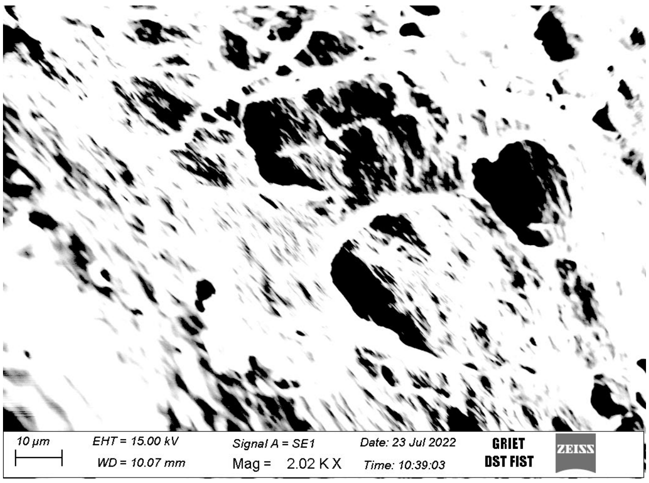


Fig. 8. (b) 30003

The increase in test temperature from room temperature to 300°C, reveals the presence of deep ductile dimples [10]; the elongated shape dimples are getting equiaxed with increase in test temperature due to partial recrystallization of the material at tensile test temperature. In addition, the overall size of the dimples increases from room temperature to 300°C. The increase in elongation values of the present samples tested at room temperature to 300°C, in agreement with the fractography features is observed. The evidence of collapse of dimples during tensile deformation is clearly observed in all the fractographs.

2.4. FE based simulation-applications

Equilibrium equations can be easily applied to solve simple 1-d beam problems. It is more complicated to solve 2-d plane or 3-d solid body problems, by applying these equations of equilibrium. The FEM approaches this problem by splitting the body into several small elements, that are connected at nodes [11]. This process is called discretisation, and collection of nodes and elements called the mesh. Discretisation is useful because the equilibrium requirement now only needs to be satisfied over finite number of discrete elements, instead of continuous over the entire body, Surface elements are a two dimensional typically used to model thin surfaces. Solid elements are used to model 3-d bodies. Choosing the right elements for the model depends on the specific scenario being analysed and require some expertise. Solid or line elements depend on how much the problem need to be simplified. For stress analysis problems, the fundamental variable most needed to be calculated is displacement at each node. If body displacement is known, it's easy to calculate secondary variables like stress and strains.

There are a lot of different analysis methods that engineers can use to solve a structural mechanisms problem, whether it's to calculate the deflection of a beam or the stresses in a flat plate. But because of complexity in geometry, loads, or materials, its often difficult to solve in this way. The Finite Element (FE) Method is a powerful numerical technique that uses computational power to calculate approximate solution to these types of problems. It's widely used technique in all major engineering industries. It could be used to check that the Satellite components survive the launch conditions, for example, or to optimize the design of automobile components, like lower control arm of the car's suspension. Many FE based software like LS Dyna code, ABACUS etc. can be utilized to analyse a wide range of solid mechanics problems including static, dynamic, buckling and model analysis. But it can be used for fluid flow, heat transfer, and electro-magnetic problems. FE technique is used by the automotive and aerospace, construction and military, manufacturing, and bioengineering industries.

2.5. LS Dyna Program code

LS-DYNA code is an advanced simulation software which was acquired by Ansys in 2019. Its origins and core competence lie in highly nonlinear transient finite element analysis (FEA) using explicit time integration. LS-DYNA code is used in the automotive, aerospace, electronics, civil engineering, military, manufacturing industries.

ANSYS and LS-DYNA are two popular engineering software tools that are used for finite element analysis. The difference between ANSYS and LS-DYNA lies in different solution procedures and time integration methods they use. ANSYS is an implicit analysis program while LS-DYNA is an explicit analysis program.

Dog-bone tensile specimen is sketched and modelled in Fusion 360 as per standard dimensions and saved as IGES file format. The IGES file is then imported to finite element-based LS Dyna program code [12]. Units (tonne, mm, s, N, MPa, N-mm) are used in this work. Using Auto-Mesher option, only the surface of the specimen is meshed using mixed triangular and quad shell (surface) elements. Material cross section, materials, load curve, etc., are defined using dyna Keyword manager. In section tab, 2 mm value is entered for magnesium sheet thickness and keeping all other dyna code default values. Piecewise linear plasticity with failure (MAT_024) has been selected for material card, with other mechanical properties of the Mg alloy are entered. Experimental stress-strain curve for magnesium alloy has been imported as load curve shown in Fig. 9 and is linked to the material and section. Then the materials and section are linked to the specimen part.

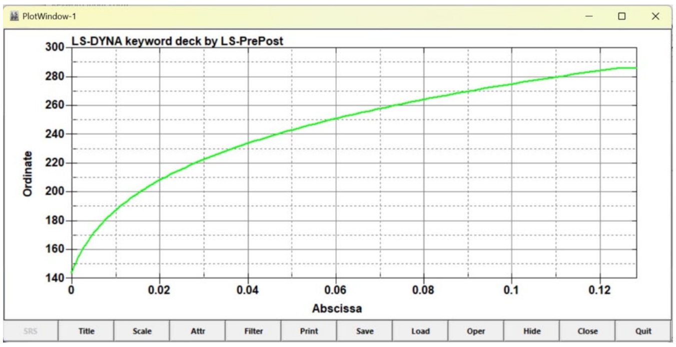


Fig. 9. Stress strain curve used in the dyna code

As the tensile specimen is fixed at one end and free at the other end, set of fixed and moving nodes are created using **create entity** option. **boundary_spc_set**, is used to arrest all the degree of freedoms (dof) of all the fixed set of nodes. Using, **prescribed_motion_set**, only one dof i.e. x-translation motion is allowed for the moving nodes. Except x-translational motion for moving nodes, other dof need to be arrested by using again **boundary_spc_set**. Here, it's essential to define velocity or displacement curve for the translation motion which has been allowed for moving nodes. The velocity curve used here for the translational motion of moving nodes is shown in Fig. 10.

Constant velocity 0.5 mm/ms has been selected for 1000 ms. The total running simulation or termination time should be less than this 1000 ms. Output cards like Control and Database need to be defined. In database, the parameters like Energy, Shell, Termination time and Timestep are inputted. In database, many cards like ASCII, binary d3plot, extent-binary etc are entered.

The termination time selected as 35 ms. Using dyna program manager, the model is run for simulated results. Most

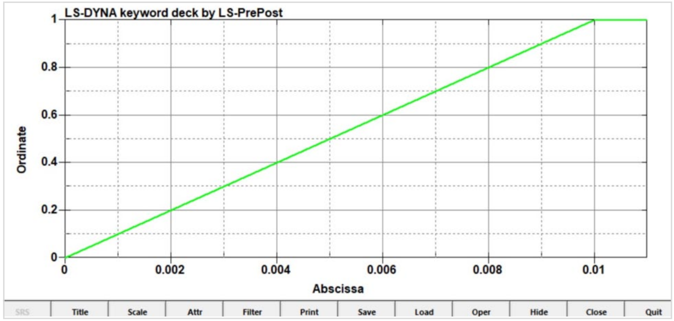


Fig. 10. Load curve/velocity curve used in the program code

importantly effective plastic strain (e.p.s) and effective stresses (Tresca and Von Mises) are recorded, using fringe components in LS Post. LS Dyna is an explicit dynamic type of solver, unlike other solvers ABACUS, ANSYS etc. Explicit dynamic mean, defining time dependent load instead of applying constant load.

History option in LS Post can be used to save the output results, for example, effective plastic strain vs. time, effective stress vs. time etc. The program files then be saved as Microsoft excel (.csv) file format for further graphing, analysis, and printing. Tresca and Von Mises effective stress-plastic strain graphs are compared in Fig. 11.

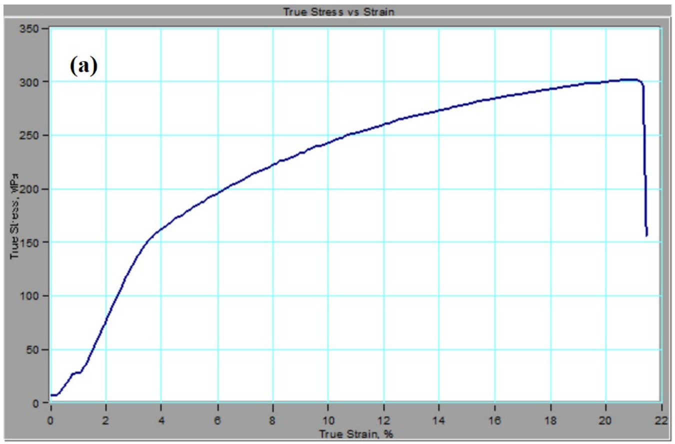


Fig. 11(a). EPS vs Effective Stress (experimental) curve

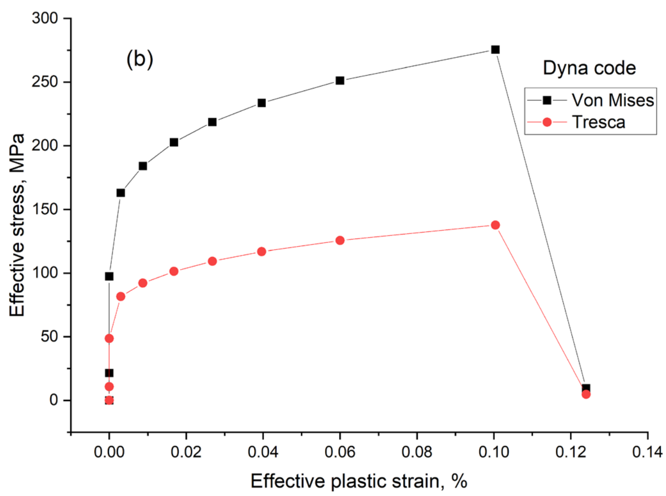


Fig. 11(b). EPS Vs Effective stress (Dyna code) curves

These graphs are corresponded to few elements near the fracture zone in the model. These simulated results are consistent with the experimental observations.

2.6. Serrated plastic flow

Plastic deformation region of true stress-strain curves of the tensile samples tested at 200, 250, 300°C, reflect the presence of serrations. The serrations are associated with the dynamic strain aging. A magnified view of these regions is shown Fig. 12.

The serrated flow curves in present case consists of small stress amplitude with the band propagation [13]. Both the amplitude and extent of band propagation increase with increase in tensile testing temperature and strain rate.

The observed serrated flow in present case is due to a combined interactions of dislocations with deformation twins and strain fields associated with the solute atoms [14]. It is known that the hexagonal close packed materials deform by twinning which is being produced during tensile deformations. Interestingly, it is also inferred that if the twinning occurs during tensile test, it results in the formation of serrations in stress-strain curves. The low stress amplitude in serrated flow region may probably be attributed to the small differences in atomic radius among the constituent atoms.

Rodriguez has classified the serrated plastic flow behaviour of different materials based on the nature of serrations [Ref]. He has identified five distinct types of serrations namely A, B, C, D, and E. The nature of serrations observed in present case predominantly belongs to the type E. Type D serrations are also appeared in a few cases along with the type E at lower strains. It has been mentioned that the type E serrations are similar to type A with little or no hardening during band propagation. Present results also point towards the similar nature of serrated flow of the AZ31B magnesium alloy during tensile deformation at elevated temperatures.

2.7. Machine Learning predictions

The experiments were carried out based on Machine Learning models developed using Phython in Google Colab environment. The authors have tied with four kinds of Machine Learning models including Linear Regression, Multilinear Regression, Random Forest with 1000 estimators and XGB Regression.

Machine learning, which has proven to be an excellent choice for prediction in fields such as finance, natural language processing, weather forecasting, and computer vision, has slowly made its way to materials science in recent years. With the advent of machine learning models and artificial intelligence, which have regained many positions at the forefront of research, much

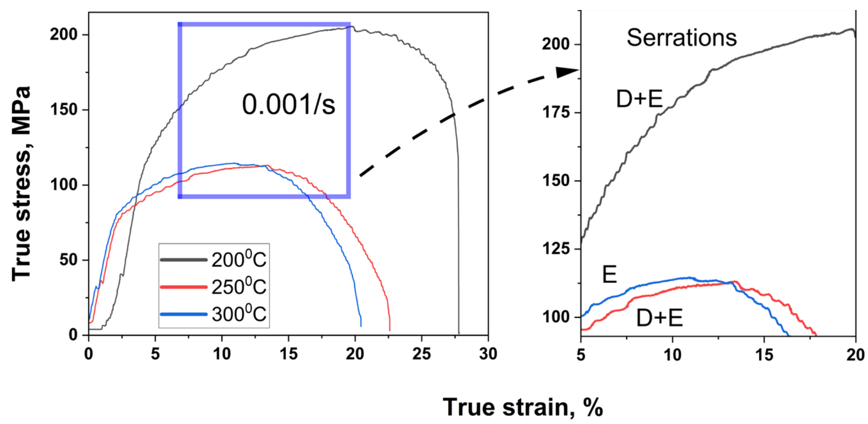


Fig. 12(a). Serrated plastic flow at diff temp

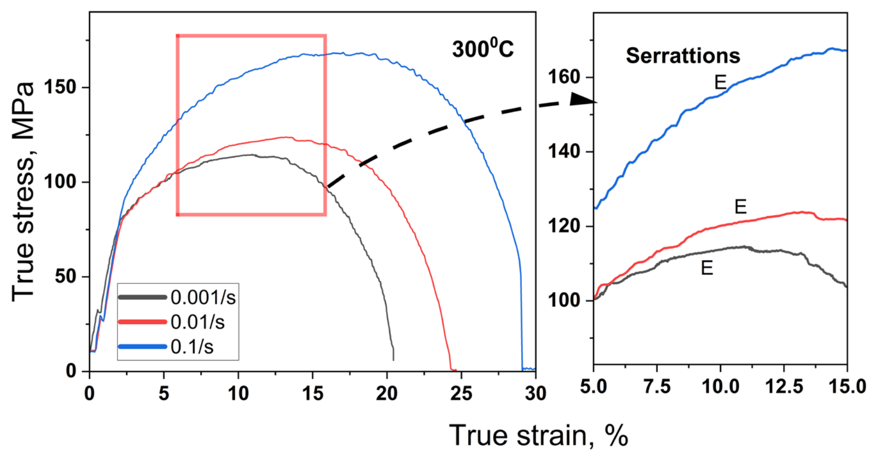


Fig. 12(b). Serrated plastic flow at diff strain rates work has been done in developing machine learning models to study various alloy properties. Machine learning mechanisms are highly dependent on the data set used to train the model [15]. The data set consists of 5 parameters in input, Temperature, Str, Rolling, Time, Load and ultimately Displacement as Target variable. A total of 16399 rows consisting of 5 columns data is used as Data set for the models developed during the current research. The description of data used is as shown in the Fig. 13(a). The data was cleansed manually, and no null values were identified as shown in Fig. 13(b). The data accuracy and their RSME values are shown in TABLE 3 and TABLE 4.

(a)

	Temp	STr	Rolling	Time	Load	Displacement
count	16399.000000	16399.000000	16399.000000	16399.000000	16399.000000	16399.000000
mean	215.854869	0.029745	45.351241	82.585007	1.495508	5.311021
std	84.400762	0.043280	36.103243	82.347903	0.897143	3.511881
min	24.000000	0.001000	0.000000	0.009470	-0.050059	-0.001354
25%	200.000000	0.001000	0.000000	6.104660	0.961200	2.406002
50%	250.000000	0.001000	45.000000	48.800110	1.445616	5.016476
75%	300.000000	0.100000	90.000000	151.398800	2.043793	7.657894
max	300.000000	0.100000	90.000000	292.399400	3.385417	16.970660

Fig. 13(a)

```
print(data.info())
```

(b)

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 16399 entries, 0 to 16398
Data columns (total 6 columns):
 #   Column        Non-Null Count  Dtype
---  ------        --------------  -----
 0   Temp          16399 non-null  int64
 1   STr           16399 non-null  float64
 2   Rolling       16399 non-null  int64
 3   Time          16399 non-null  float64
 4   Load          16399 non-null  float64
 5   Displacement  16399 non-null  float64
dtypes: float64(4), int64(2)
memory usage: 768.8 KB
None
```

Fig. 13(b). Other data information

TABLE 3

Accuracy obtained in % for different regression models

Sl. No.	Model	Accuracy % obtained
1	Linear Regression	28.87
2	Random Forest with 1000 estimators	98

TABLE 4

RSME Values observed

Sl. No	Model	RMSE Values observed
1	Multilinear Regression	2.9824
2	XGBRegressor	0.2393

Actual and regression predicted results, Temperature vs. Displacement and Strain vs. Displacement are shown in Fig. 14(a), Fig. 14(b) and Fig. 14(c) respectively.

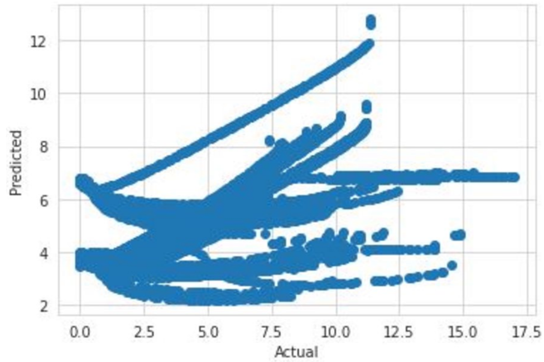


Fig. 14(a). Regression Vs Actual predicted

```
sns.barplot(x='Temp',y='Displacement', data=data,
            hue='STr')
plt.ylim(top=10)
plt.show()
```

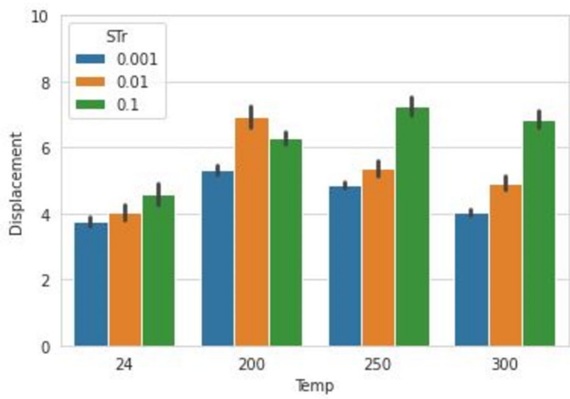


Fig. 14(b). Temp Vs Displacement (Bar plot)

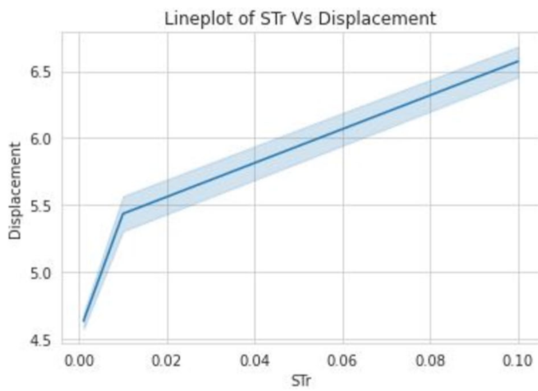


Fig. 14(c). Strain Vs Displacement line plot

3. Results and discussion

High temperature uni-axial tensile tests have been conducted on AZ31B magnesium alloy of 2 mm thick sheet, to measure material's formability using hot forming machine using hemi spherical punch. The results are given in TABLE 1. The major points of the uni-axial tensile tests are summarised below.

- At high strain rates (0.1 mm/s) and at room or low temperatures, the % elongation achieved i as low as 7%.

- At slower strain rates (0.001 mm/s), and at room or low temperatures, the % elongation observed is as high as 20%. However, rolling direction is the favourable condition.
- At slower strain rates and at moderate temperatures, about 200°C or above, even higher elongations of 21-32% are attained.
- Stable yield and elastic modulus can be calculated from stress-strain curves.
- At test temperatures above 300°C, attaining even higher % elongations of 40-50 is possible with proper lubrication applied on the specimen.
- Serrations and their influence on the formability has been outlined.
- Both the amplitude and extent of band propagation increase with increase in tensile testing temperature and strain rate.

Formability predictions from LS Dyna code are consistent with the experimental results. An attempt has been made in predicting material's formability using Machine learning models. The experimental data set is used in building the regression models. Random Forest predictions have displayed the better accuracy and least error. The following inferences are made from both the experimental and predictions by software codes:

- Dyna code simulations are close to the realistic experimentation with solid elements and fine meshing; however, run time limits the usage of the code to the maximum extent.
- Effective plastic strain and effective stress curves obtained from Dyna code program and experimental results are in near agreement with less than 10-15% deviation.
- Formability capabilities of Mg alloy sheet beyond 300°C appear to be quite promising.
- Both the amplitude and extent of band propagation increase with increase in tensile testing temperature as well as strain rate; however, it is yet to be identified with the code.

3.1. Machine learning - results

The experiments were carried out based on Machine Learning models developed using Phython in Google Colab environment. The authors have tied with four kinds of Machine Learning models including Linear Regression, Multilinear Regression, Random Forest with 1000 estimators and XGB Regression.

- The results obtained in the initial trials are not much encouraging as Linear Regression yielded only 28.87% accuracy.
- Multilinear regression as used and the RMSE value observed is to be as 2.9824.
- Experimentation was also done using XGBost GridSearchCV with n estimators 100, 200 and max depth of 10,15,20,25. It is observed that at maximum depth of 10 and estimators of 200 best parameters are found and a Lowest Root Mean Square Error (RMSE) is recorded as 0.2393 as shown in the Figure X. The root mean square error for test data set is found to be 0.22.
- To improvise the efficiency of classifier further, the authors experimented using Random Forest Decision tree algorithm considering an estimator factor of 1000. The accuracy recorded is a huge jump from 28.87 to 98%. The data is split in 70:30 for training and testing purpose when 98% accuracy was achieved.

4. Conclusion

Uniaxial stretch forming has been carried out at different temperatures on Magnesium based AZ31 alloy sheet and the experimental findings are summarised. The increase in temperature increases the elongation of the material. Interestingly serrated plastic flow has been observed at very low and at moderate temperatures.

LS dyna code analysis and Machine learning predictions are graphically presented, compared, and interpreted systematically. It has been shown that ML models and Dyna code simulations are eventually minimizing the need of number of physical experiments to be conducted and consistent with the experimental results. Further, it has been concluded that the Random forest regression approach could evidently best suited in the prediction of material formability of the present alloy.

REFERENCES

[1] B. Viswanadhapalli, V.K. Bupesh Raja, Application of Magnesium Alloys in Automotive Industry – A Review. In Emerging Trends in Computing and Expert Technology, Cham, 519-531 (2020).

[2] L.C. Whitmore et al., Macro to nano: a microscopy study of a wrought magnesium alloy after deformation. European Journal of Physics **40**, 4, 045501, Jun. (2019).
DOI: https://doi.org/10.1088/1361-6404/ab168a

[3] Y. Li et al., Effect of Loading Direction on the Tensile Properties and Texture Evolution of AZ31 Magnesium Alloy. Crystals **11**, 10, 1193, Sep. (2021).
DOI: https://doi.org/10.3390/cryst11101193

[4] B. Shi, C. Yang, Y. Peng, F. Zhang, F. Pan, Anisotropy of wrought magnesium alloys: A focused overview. Journal of Magnesium and Alloys **10**, 6, 1476-1510 (2022).
DOI: https://doi.org/10.1016/j.jma.2022.03.006

[5] V. Balaji, V.K.B. Raja, K. Palanikumar, Ponshanmugakumar, N. Aditya, V. Rohit, Effect of heat treatment on magnesium alloys used in automotive industry: A review. Materials Today: Proceedings **46**, 3769-3771(2021).
DOI: https://doi.org/10.1016/j.matpr.2021.02.017

[6] S. Jiang, Z. Jiang, Q. Chen, Deformation twinning mechanism in hexagonal-close-packed crystals. Scientific Reports **9**, 1, 618, Jan. (2019).
DOI: https://doi.org/10.1038/s41598-018-37067-8

[7] P. Sonia, J.K. Jain, K.K. Saxena, Influence of Severe Metal Forming Processes on Microstructure and Mechanical Properties of Mg alloys. Advances in Materials and Processing Technologies, 1-24, Sep. (2020).
DOI: https://doi.org/10.1080/2374068X.2020.1802554

[8] G. Ambrogio, C. Bruni, S. Bruschi, L. Filice, A. Ghiotti, M. Simoncini, Characterisation of AZ31B magnesium alloy formability in warm forming conditions. International Journal of Material Forming **1**, 1, 205-208, Apr. (2008).
DOI: https://doi.org/10.1007/s12289-008-0027-y

[9] L. Wang, Q. Qiao, Y. Liu, X. Song, Formability of AZ31 Mg alloy sheets within medium temperatures. Journal of Magnesium and Alloys **1**, 4, 312-317 (2013).
DOI: https://doi.org/10.1016/j.jma.2014.01.001

[10] F. Shehata, M.J. Painter, R. Pearce, Warm forming of aluminium/magnesium alloy sheet. Journal of Mechanical Working Technology **2**, 3, 279-290, Dec. (2078).
DOI: https://doi.org/10.1016/0378-3804(78)90023-2

[11] H. Palaniswamy, G. Ngaile, T. Altan, Finite element simulation of magnesium alloy sheet forming at elevated temperatures. Journal of Materials Processing Technology **146**, 1, 52-60 (2004).
DOI: https://doi.org/10.1016/S0924-0136(03)00844-6

[12] X. Xu, L. Wang, G. Zhu, X. Zeng, Predicting Tensile Properties of AZ31 Magnesium Alloys by Machine Learning. JOM **72**, 11, 3935-3942, Nov. (2020).
DOI: https://doi.org/10.1007/s11837-020-04343-w

[13] P. Rodriguez, Serrated plastic flow. Bulletin of Materials Science **6**, 4, 653-663, Sep. (1984).
DOI: https://doi.org/10.1007/BF02743993

[14] Q. Yang, C. Xue, Z. Chu, Y. Li, L. Ma, Molecular dynamics simulation of the effect of solute atoms on the compression of magnesium alloy. Applied Physics A **127**, 6, 482, Jun. (2021).
DOI: https://doi.org/10.1007/s00339-021-04636-0

[15] X. Xu, L. Wang, G. Zhu, X. Zeng, Predicting tensile properties of AZ31 magnesium alloys by machine learning. Jom, **72** (11), 3935-3942 (2020).