THE BEHAVIOR OF AZ31 MAGNESIUM ALLOY SHEETS AT TENSILE TESTING

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Abstract: The tests were done on AZ31 magnesiun alloy sheets. Only flat test specimens were used and tests were performed for three different sizes. The specimens were used according to SR EN ISO 527-4: 2000 dumbbell type. Two attempts were made for 0º, 45º and 90º relative to the rolling direction. In total, 6 specimens were used to examine the behavior of AZ31 magnesium alloy sheets at 1mm/min and 10mm/min. For tensile elastic limit the resulted values were 102.91, 162.40 and 182.59 MPa. For anisotropy coefficient the resulted values were 0.44, 0.50 and 0.11. For tensile strength the resulted values were 15808, 35923 and 33858 Mpa.

Key words: tensile strength, tensile elastic limit, Young's modulus, Poisson's ratio, yield strength, strain-hardening characteristics.

1. INTRODUCTION

Some of the most important problems that magnesium alloy sheets poses are those related to malleability. The processing of these alloys differs greatly from the steel and aluminum alloys that are most used in the industry. The significant advantage of magnesium alloys is that of lower density in comparison with the commonly used alloys - aluminum and steel, [1, 2].

The tensile test is one of the most important mechanical test used to study the behavior of any material. This test allows determining the strength, plasticity and material breakage characteristics. The test consists in breaking under a traction force the specimen and recording the force variation curve F with the deformation Δl [3, 4]. Test specimens can be made or without gripping heads, being the most obvious results during the tensile tests is obtained with specimens having gripping heads. The main parameters that can be determined from the tensile test are: tensile strength, tensile elastic limit, Young's modulus, Poisson's ratio, yield strength, strain-hardening characteristics and stress-strain curve. If the specimen is subjected to progressively increasing tensile force it reaches the ultimate tensile stress and then necking and elongation occur rapidly until fracture. If the specimen is subjected to progressively increasing length it is possible to observe the progressive necking and elongation, and to measure the decreasing tensile force in the specimen, [5].

In this paper it is made a detailed assessment of the mechanical properties of the AZ31 magnesium alloy sheets in order to find the conditions and the most efficient way in which this type of alloy can be used, taking into account the advantages and disadvantages that it can offer.

2. EXPERIMENTAL

Lloyd EZ50 machine was used to do the tensile tests. Tests were performed on flat AZ31 magnesium sheet specimens and steel soldur 340 sheet specimens with gripping heads. The specimens used for the traction tests are in accordance with SR EN ISO 527-4: 2000. The shape of the specimens is shown in fig. 1 and the constructive dimensions are presented in table 1.

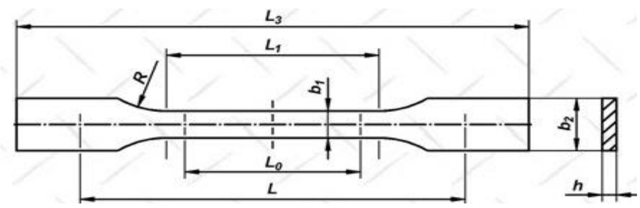

Fig. 1. Tensile test specimen, [6]

Table 1. Constructive dimensions

L_3 (mm)	b_2 (mm)	L_1(mm)	b_1 (mm)	R (mm)
150	17	75	12	R20

To analize the deformations, Epsilon Model 3542 axial extensometer, was used. To study the behavior of the AZ31 magnesium alloy sheets were used and two different deformation speeds during the tests. The two deformation speeds used were 1mm/min si 10 mm/min. Two attempts were made for three different angles to the sheet rolling direction, respectively 0º, 45º and 90º. In total 6 specimens were used to determine the mechanical characteristics at a speed of 1mm/min. The same number of attempts was made to determine the mechanical characteristics at a speed of 10mm/min.

3. RESULTS AND DISCUSSIONS

The mechanical characteristics of the tested material were determined for each test specimen subjected to the tensile test. The results are presented in table 2 for each specimen tested. The results presented in table 2 are for tests done at 1mm/min deformation speed.

Table 2. Specimen mechanical parameters (v = 1mm/min)

Parameter / Specimen	Tensile elastic limit [MPa]	Yield strength [MPa]	Tensile strength [MPa]	Anisotropy coefficient	Elongation at breaking [%]	Poisson's ratio	Young's modulus [MPa]
1	2	3	4	5	6	7	8
0º as rolling direction							
1	102.91	152.49	231.43	0.44	9.33	0.48	15808
2	94.58	165.61	252.32	0.56	8	0.70	20919
45º as rolling direction							
1	162.40	175.19	257.12	0.50	8	0.62	35923
2	169.86	177.94	255.58	0.40	6.67	0.60	31641
90º as rolling direction							
1	182.59	203.08	306.70	0.11	6.67	0.16	33858
2	185.22	198.77	301.01	0.22	8	0.28	33048

In figure 2 it is shown the stress-strain diagram for the both specimens used at tensile test at 0º as rolling direction. For drawing the curve, an average of the values obtained in the two tests was made. The graph shows the real curve resulting from the tests and the engineering curve.

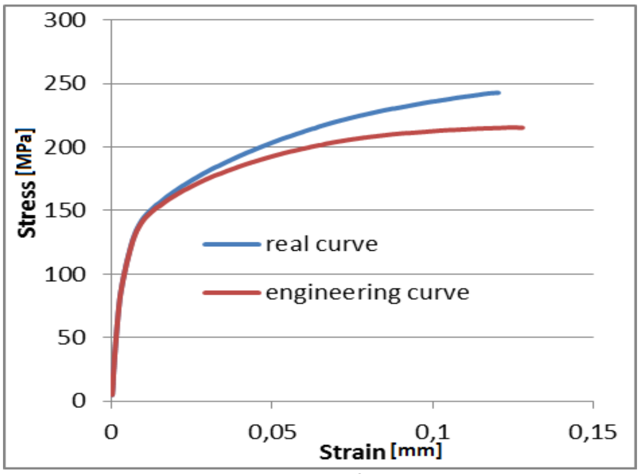

Fig. 2. Stress-strain diagram for tested specimens at 0º as rolling direction

As a result of the performed tests at the maximum stress of 242MPa a deformation of 0.12 mm was obtained. It can be noticed that there is a difference between the real curve determined and the engineering curve. At the engineering curve for a 0.12 mm deformation it should be obtained with a stress of 215 MPa.

Figure 3 shows the stress – strain diagram for the two test specimens used at tensile test at 45° as rolling direction. For drawing the curve, an average of the values obtained in the two attempts was made. The graph shows the real curve resulting from the tests and the engineering curve.

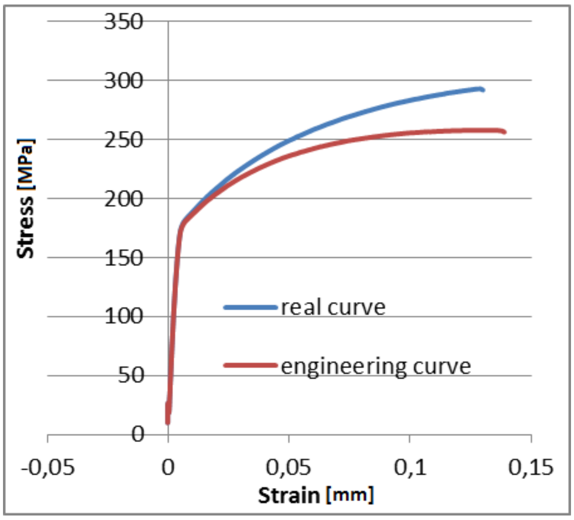

Fig. 3. Stress-strain diagram for tested specimens at 45º as rolling direction

In figure 4 it is shown the stress-strain diagram for the both specimens used at tensile test at 90º as rolling direction. For drawing the curve, an average of the values obtained in the two tests was made. The graph shows the real curve resulting from the tests and the engineering curve.

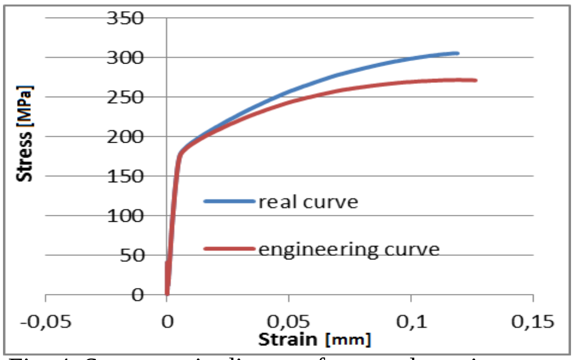

Fig. 4. Stress-strain diagram for tested specimens at 90º as rolling direction

As a result of the performed tests at the maximum stress of 305 MPa, a deformation of 0.12 mm was obtained. It can be noticed that there is a difference between the real curve obtained and the engineering curve. For the engineering curve a deformation of 0.12mm should be obtained with a stress of 270 MPa. The determined mechanical characteristics of the specimens tested in tensile test at a 10mm/min deformation speed are shown in Table 3.

Table 3. Specimen mechanical parameters (v = 10mm/min)

Parameter / Specimen	Tensile elastic limit [MPa]	Yield strength [MPa]	Tensile strength [MPa]	Anisotropy coefficient	Elongation at breaking [%]	Poisson's ratio	Young's modulus [MPa]
1	2	3	4	5	6	7	8
0° as rolling direction							
1	121.94	191.74	283.83	0.28	9.46	0.59	36382
2	82.56	193.35	276.40	0.45	8.53	0.52	36838
45° as rolling direction							
1	170.99	184.95	274.08	0.20	8.66	0.23	29720
2	185.28	195.18	250.69	0.30	7.33	0.41	29092
90° as rolling direction							
1	202.78	208.13	296.04	0.11	8.01	0.28	27378
2	182.93	207.59	313.74	0.11	6.67	0.16	37234

In figure 5 it is shown the stress-strain diagram for the both specimens used at tensile test at 0° as rolling direction. For drawing the curve, an average of the values obtained in the two tests was made. The graph shows the real curve resulting from the tests and the engineering curve.

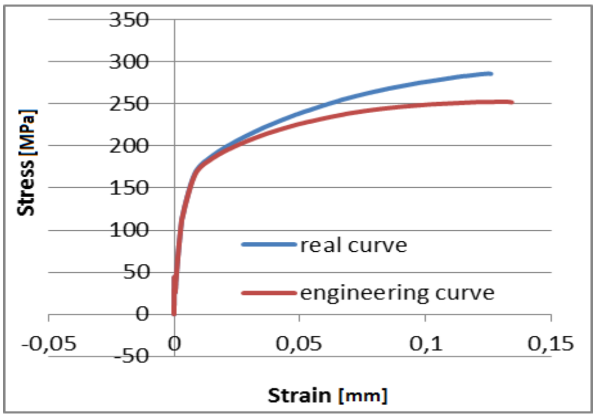

Fig. 5. Stress-strain diagram for tested specimens at 0° as rolling direction

As a result of the performed tests at the maximum stress of 285 MPa, a deformation of 0.12 mm was obtained. It can be noticed that there is a difference between the real curve obtained and the engineering curve. For the engineering curve a deformation of 0.12mm should be obtained with a stress of 252 MPa. It can be noticed that there are also differences between the two deformation speeds for the same angle as rolling direction.

In figure 6 it is shown the stress-strain diagram for the both specimens used at tensile test at 45° as rolling direction. For drawing the curve, an average of the values obtained in the two tests was made. The graph shows the real curve resulting from the tests and the engineering curve.

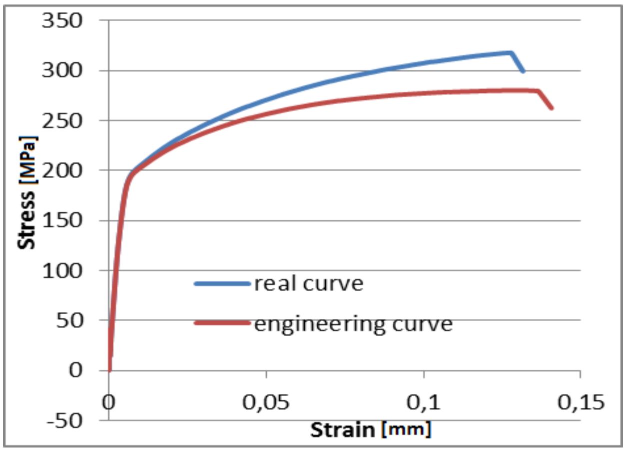

Fig. 6. Stress-strain diagram for tested specimens at 45° as rolling direction

In figure 7 it is shown the stress-strain diagram for the both specimens used at tensile test at 90° as rolling direction. For drawing the curve, an average of the values obtained in the two tests was made. The graph shows the real curve resulting from the tests and the engineering curve.

The tests results were recorded in Table 2 for the deformation speed of 1mm/min and in Table 3 for the deformation speed of 10mm/min. Graphs 2, 3 and 4 show the stress-strain curves for the tests performed at 0°, 45° and 90° as rolling direction. In the first 3 graphs, the tests were performed at 1mm/min. In order to analyze the behavior of the tested material in these graphs, the engineering curve was also drawn, so that the difference between the theoretical behavior of the test material and the actual behavior obtained after the tensile test can easily be observed.

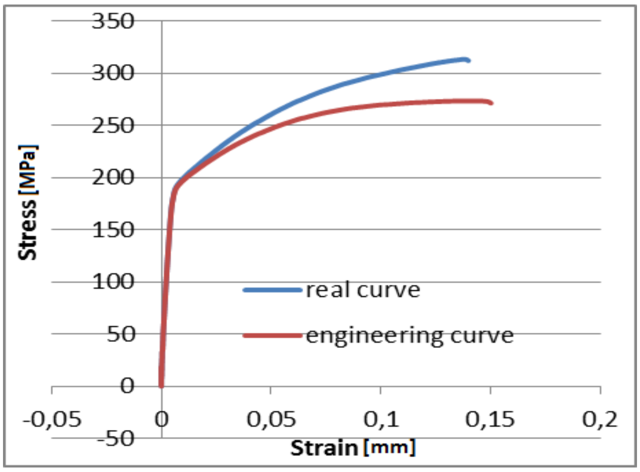

Fig. 7. Stress-strain diagram for tested specimens at 90º as rolling direction

In order to make a comparison between these graphs, the graph in Figure 8 was drawn where only the values of the real curve were selected from the three graphs shown above, and so it can be observed the behavior of the material for the tests performed at 0º, 45º and 90º as rolling direction.

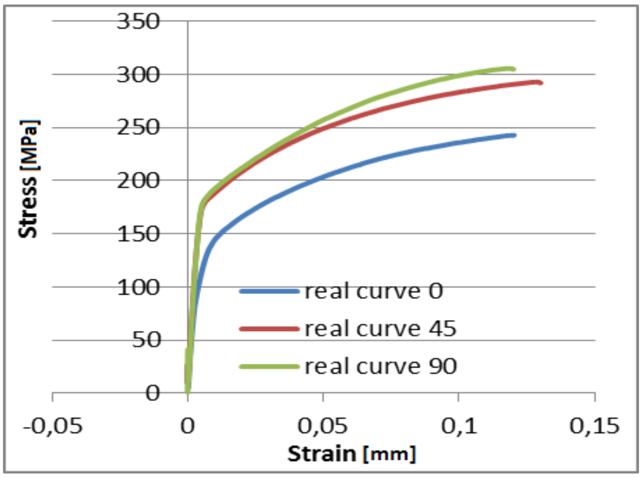

Fig. 8. Real curves for the 3 rolling directions done at 1mm/min

It was noticed that the material streched best at tensile test when it was tested in the same direction as the sheet rolling direction, at 0º. When tested at 45° as the sheet rolling direction it was observed that the material deformed more heavily, the stress increased significantly from about 240 MPa to about 290 MPa. At the tests performed at 90º as rolling direction of the sheet it was observed that the material deformed even more difficult than in the previous situations so that the stress reached values of 310 MPa and the length of the deformation was shorter.
Graphs 5, 6 and 7 show the stress-strain curves for the tests performed at 0º, 45º and 90º as rolling direction of the magnesium sheet. In these three graphs the tests were performed at a speed of 10mm/min. In order to analyze the behavior of the tested material in these graphs, the engineering curve was also drawn, so that the difference between the theoretical behavior of the test material and the real one obtained by the tensile test can easily be observed. To make a comparison between these graphs, it was plotted the graph in Figure 9 where only the values of the real curve were selected from the three graphs presented above, and so it can be observed the behavior of the material for the tests performed at 0º, 45º and 90º as rolling direction.

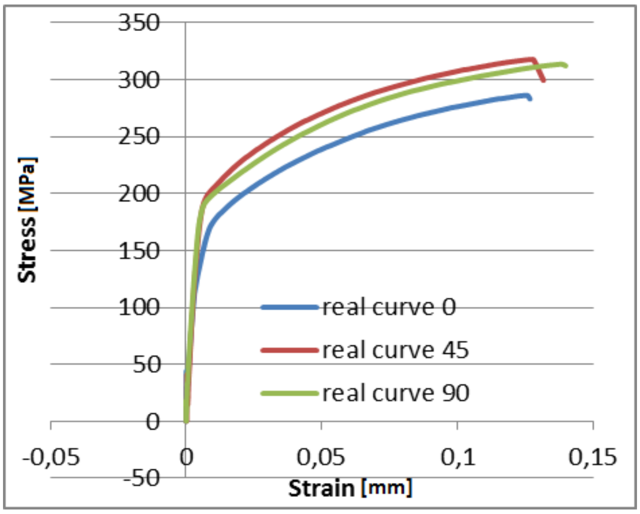

Fig. 9. Real curves for the 3 rolling directions done at 10mm/min

It was noticed that the material streched best at tensile test when it was tested in the same direction as the sheet rolling direction, at 0º. When tested at 45° as the sheet rolling direction it was observed that the material deformed more heavily, the stress increased from about 280 MPa to about 310 MPa. In the tests done at 90º as sheet rolling direction it was observed that the material deformed even more difficult than in the previous situations so that the stress reached values of approximately 315 MPa and the length of the deformation was shorter. It was also noted that the difference between the three tests was lower than in the situation shown in Figure 8. So the speed increase from 1 mm/min to 10 mm/min led to a decrease of the differences between the three tests performed.
Another analysis that has been done was that between the behavior of the material at same rolling direction but at different deformation speeds.
In Figure 10 it can be observed the behavior of the magnesium sheet at the tensile tests performed at 0º as rolling direction and the two deformation speeds. It can be observed that the material at a lower value of the defomation speed broke at a stress of about 245 MPa while at a speed of 10 mm/min a stress of about 280 MPa was required to break the specimen.
Analyzing the results obtained in the tensile tests at 45º as rolling direction and the two defomation

speeds used, 1mm/min and 10mm/min. it can be observed in Figure 11, that the behavior of the magnesium sheet specimens differs.

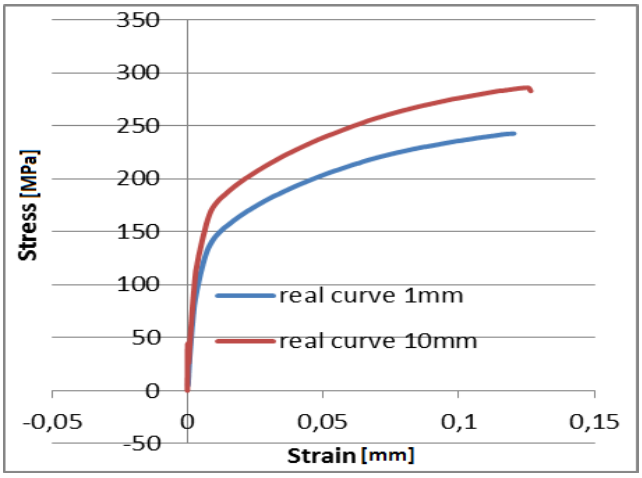

Fig. 10. Real curves for 0º as rolling direction at the two deformation speeds

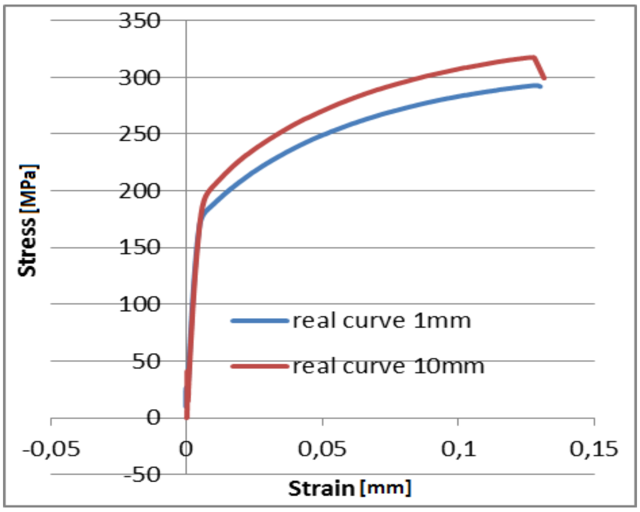

Fig. 11. Real curves for 45º as rolling direction at the two deformation speeds

It was noticed that the material at a lower value of defomation speed broke at a stress about 290 MPa while at a deformation speed of 10 mm/min a stress about 320 MPa was required. It was also observed that for the two defomation speeds the tensile elastic limit tends to be the same.
Another analysis was made on the results obtained in the tensile tests at 90º as rolling direction and the two deformation speeds used, 1mm/min and 10mm/min. This is shown in Figure 12.
It was observed that the material shows a similar behavior at the two deformation speeds during the tensile tests. There was very little difference in the maximum stress obtained before the specimen broke, about 305 MPa at a lower defomation speed and about 315 MPa at higher defomation speed. It is also noted that for the two defomation speeds the tensile elastic limit tends to be equal and the total elongation is higher for the specimen tested at a higher defomation speed.
By analising the results on the experiments done on magnesium sheets and comparing its with the results obtained on steel soldur 340 sheets, presented in table 4, we can make some remarks like advantages and disadvantages of using magnesium sheets.
The results on steel sheets were extracted from tests done earlier in 2007, [7].

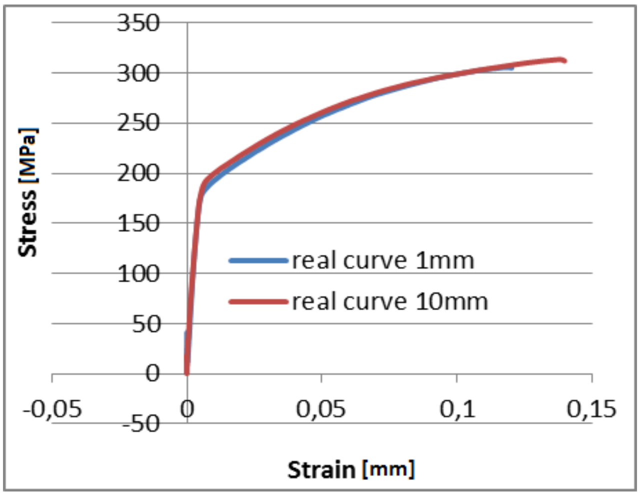

Fig. 12. Real curves for 90º as rolling direction at the two deformation speeds

Table 4. Mechanical parameters for Steel Soldur 340

Rolling direction [grd]	Young's modulus [MPa]	Yield strength [MPa]
0	198000	306
45	200000	360
90	200000	375

Rolling direction [grd]	Uniform stretching [%]	Total elongation [%]	Anisotropy coefficient [r]
0	18	34.7	0.82
45	17.5	44.1	0.77
90	18	26.1	0.81

The Young's modulus results obtained for magnesium sheets are 18363MPa and for steel sheets are 198000MPa as rolling direction. At 45 degrees as rolling direction the results are 33782MPa for magnesium sheets and 200000 MPa for steel sheets.
At 90 degrees as rolling direction the results are 33453 MPa for magnesium sheets and 200000 MPa for steel sheets.
As the results show the diffrences between these two materials are significative. It's obvious that magnesium sheets are less deformable and they have to be used for parts that don't have a complex shape and the reduced weight of the material is essential.
Regarding the results for Yield strength the differences between magnesium sheets and steel sheets aren't that big as for the Young's modulus. For

magnesium sheets the results are: 159.05 MPa for 0º as rolling direction, 176.56 MPa for 45º as rolling direction and 200.92 MPa for 90º as rolling direction. For steel sheets the results are: 306 MPa for 0º as rolling direction, 360 MPa for 45º as rolling direction and 375 MPa for 90º as rolling direction. From these results we can observe that magnesium sheets can be stretched almost like steel sheets. Still the values obtained for steel sheets are twice bigger.

The results for anisotropy coefficient for magnesium sheets are: 0.5 for 0º as rolling direction, 0.45 for 45º as rolling direction and 0.16 for 90º as rolling direction. The results for anisotropy coefficient for steel sheets are: 0.82 for 0º as rolling direction, 0.77 for 45º as rolling direction and 0.81 for 90º as rolling direction. From these results we can observe that magnesium sheet hardens twice faster than steel sheets. As the remark maid earlier in this paper parts from magnesium sheets can be maid but with simple shapes. The magnesium sheets can be stretched but not as much as steel sheets.

4. CONCLUSIONS

The tests tracked the behavior of the magnesium alloy sheets specimens on different degrees of the rolling direction. It could be seen from the data analysis that the material was deformed more easily as the metal sheet rolling direction. The deformation speed is another parameter for which the test results show that the lower the speed, the more easily the material deforms. By analyzing and combining the results obtained, in order to obtain a piece in which we need tensile resistance, we will cut the sheet metal at 90 degrees as rolling direction. If we want to get a piece with a higher coefficient of elasticity, then we will cut the sheet at 0 degrees as rolling direction. As observed during the tests, if we increase the deformation speed, the elasticity parameters will decrease, meaning the pice will become stiffer and may crack. This is an inconvenience in industrial processes because it means there must be more processing times for the part to maintain its elasticity properties.

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