Effect of Friction Stir Processing on the Dynamic Behavior of Aluminum Alloys AA6061

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ABSTRACT

AA6061 aluminum alloy (Al–Mg–Si alloy) has a wide acceptance in the fabrication of light weight structures that requiring a high strength-to-weight ratio and good corrosion resistance. The aim of the present work is to investigate the FSP (friction stir processing) as a potential processing technique for aluminum alloys because of various advantages it offers over other processes. A modal analysis technique used to study effect of changing mechanical work conditions (cutting speed and feed rate) on the dynamic behavior of aluminum alloy. The studying appeared that, the natural frequency of AA6061 aluminum alloy piece gave a good result at high cutting speed and medium value of feed rate. Also, the damping value decrease with increasing the cutting speed and feed rate.

Keyword: AA6061 alloy – Modal analysis – Cutting speed – Feed rate

INTRODUCTION

Selection of material with specific properties is the key parameter in many industrial applications, especially in the aircraft and automotive industries [1]. However, processing of such alloys with specific properties, like high strength, suffers from certain limitations in terms of cost and time of production, apart from the reduction in ductility [2]. High strength accompanied by high ductility is possible with materials having fine and homogenous grain structures [3]. Hence there arises a necessity to develop a processing technique that would produce a material with small grain size that satisfies the requirements of strength and ductility as well as the cost and time of production [4]. There are new processing techniques like Friction Stir Processing (FSP) being developed for this purpose in addition to the improvements in conventional processing techniques like the Rockwell process, powder metallurgy technique [5]. FSP offers many advantages over the conventional and also the newer techniques of material processing which include being a single step process, use of simple and inexpensive tool, no expensive time-consuming finishing process requirement, less processing time, use of existing and readily available machine tool technology, suitability to automation, adaptability to robot use, being energy efficient and environmentally friendly [6]. Though the limitations of FSP are being reduced by intensive research and development, it still has few limitations that include rigid clamping of the work pieces, backing plate requirement, and the keyhole at the end of each pass [7]. These above-mentioned features of FSP make it a potential processing technique not only of aluminum alloys for various industrial applications especially for the FSP but also in the fields of surface engineering, like metal-matrix composite production.

One of the potential applications of FSP is in superplastic forming, which is a net shape forming technique [8]. Hence it can be said that the widespread use of FSP of aluminum alloys is hampered by the slow optimum strain rate required for super plasticity, particularly in commercial aluminum alloys as well as fine grain size requirement that can be attributed to the lack of simple, fast and cost-effective material processing techniques. Hence there have been efforts made not only to improve the existing conventional material processing techniques but also to develop some new techniques.

Both the hot-rolled and friction-stirred samples experience dynamic recrystallization, and the processing factors affect the tensile deformation and vibration fracture resistance of the specimens [9]. The vibration fracture resistance depends on vibration test conditions and material characteristics, respectively.

EXPERIMENTAL WORK

A plate of AA6061 (Al-Zn-Mg-Si) aluminum alloy with chemical composition as found in Table 1, and the plate form dimensions of [6000 mm (length) × 70 mm (width) × 10mm (thickness)] as shown in Figure 1 were used. The plat was fabricated related to (FSP) process in a single pass using a steel tool.

Table 2.1. Chemical Composition of A6061 alloy.

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Alloy	chemical compositions (weight %)									
	Si	Fe	Cu	Mg	Mn	Cr	Zn	Ti	Other	Al
AA6061	0.4	0.7	0.15 to 0.4	0.15	0.8 to 1.2	0.04 to 0.35	0.25	0.15	0.05 to 0.15	Bal.95.85

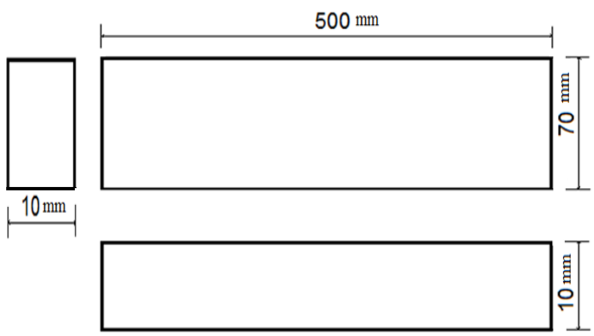


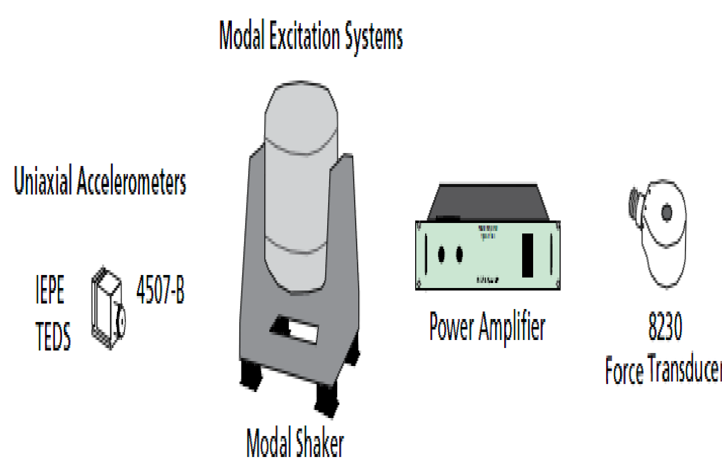
Figure 1: A Schematic Drawing of the FSP Specimens.

The FSP were conducted using vertical milling machine using three different tool rotation speeds, typically, 500, 800 and 1000 rpm. Also, three traverse speeds (feed rates) were used typically, 5, 10 and 15 mm/min. In all experiments, the tool angle was fixed to 3° and the tool down force was held constant by keeping constant depth of the tool immersed in the AA6061 plate. The depth was about 9 mm.

For dynamic test two ways of performing Experimental Modal Analysis were used, Classical Modal Analysis and Operational Modal Analysis. Classical Modal Analysis used to calculate the frequency response functions by measuring the input forces and output responses of the structure. In the other hand, the output responses can be measured by using operational modal analysis, only the output responses are measured.

The Experiment tools and its connections are shown in Figure 2, are;

1- Vibration Exciter (shaker), B&K type 4827 with frequency range (2-5000Hz), and rated force (70-100N).
2- Accelerometer Transducer, B&K type 4507-B with frequency range (0.3-6000Hz).
3- Piezoelectric Force Transducer B&K type 8230 with force range (880N) and sensitivity (110mV/N),
4- 4/2 input/output Generator Module and Modal analysis software.



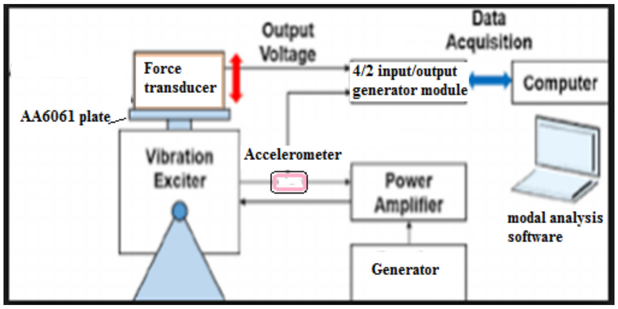


Figure 2: The Experiment Tools

The modal analysis for the A6061 aluminum alloy plate, the first step of measuring the setup geometry is done by dividing the measured part into numbers of row and columns. In that work the measured part is 150x35 mm, then we divided it into two rows and five columns as shown in Figure 3.

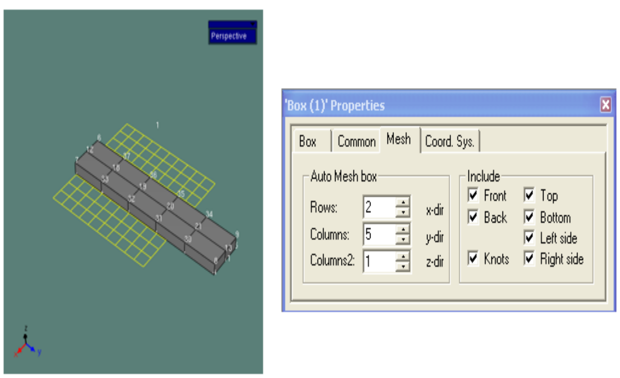
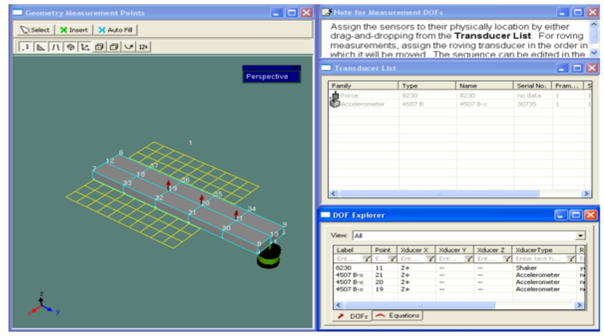


Figure 3: The Geometry Setup.

The second step of measuring is Measurement Degree of Freedoms (DOFs) by indicate the position of the shaker and the sensors as shown in Figure 4.



Measurement	Signal	DOF, Point No.	DOF, direction	DOF, component
STS Measurement 1	4507 B-x	21	+Z	
STS Measurement 1	8230 Ref.	11	+Z	
STS Measurement 2	4507 B-x	20	+Z	
STS Measurement 2	8230 Ref.	11	+Z	
STS Measurement 3	4507 B-x	19	+Z	
STS Measurement 3	8230 Ref.	11	+Z	

Figure 4: The Measurement (DOFs).

The final step is the Analysis & Shaker Setup by choosing the frequency and the excitation waveform as shown in Figure 5.

Analysis & Shaker Setup

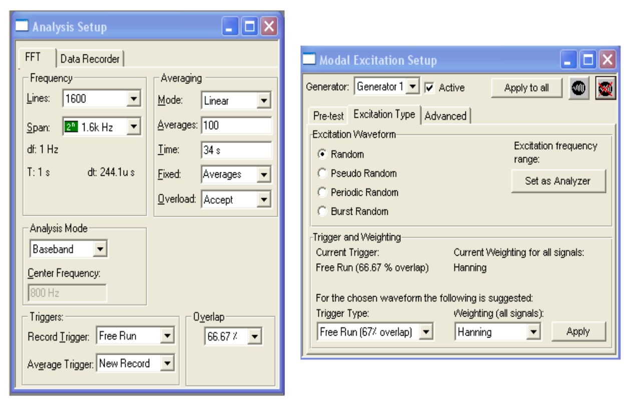


Figure 5: The Analysis & Shaker Setup.

THE DYNAMIC TEST MEASUREMENTS RESULTS

The spectrum of the modal analysis for AA6061 aluminum alloy plate at different working conditions (rotational and travers speeds) presented in the following figures. The rotational speed (S) changed from 500, 800, and 1000 r.p.m also the travers speed (F) had the values 5, 10, and 15 mm/min.

1. **<u>For Base</u>**

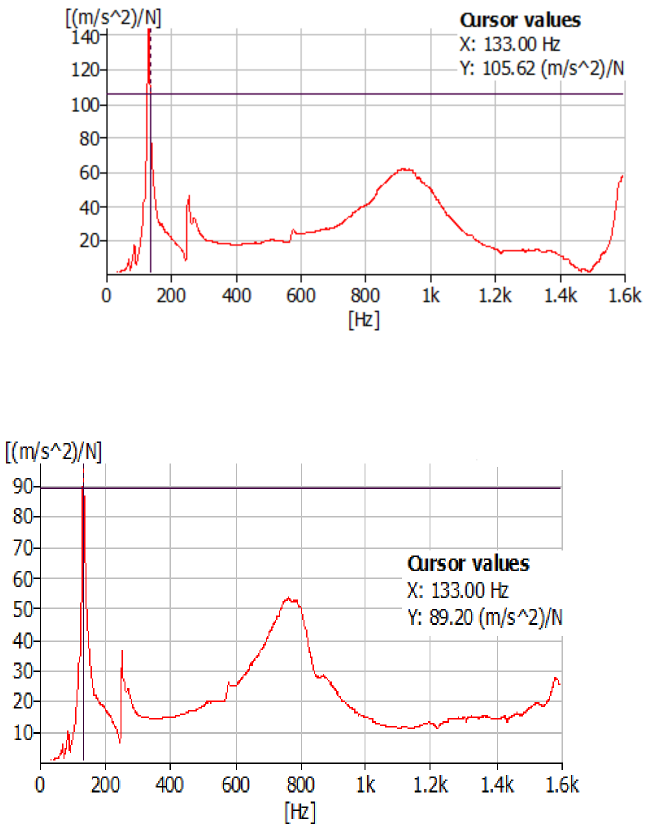


Figure 6: The Spectrum of Base Plate Material

2. **<u>For S500 F5</u>**

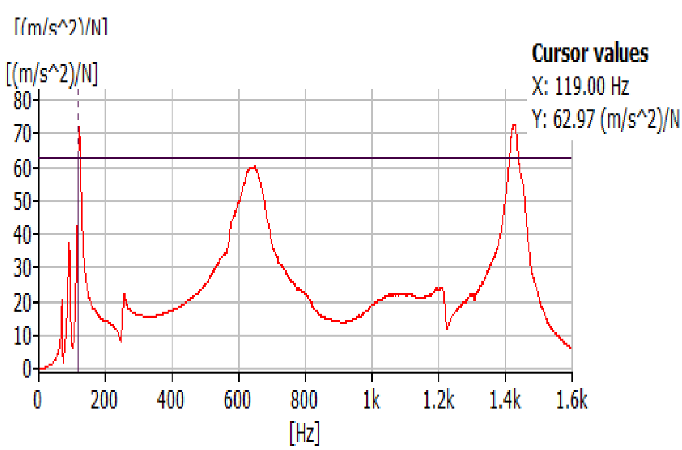


Figure 7: The Spectrum of AA6061 Plate at Rotational Speed (S) 500 r.p.m and Travers Speed (F) 5mm/min

3. **<u>For S500 F10</u>**

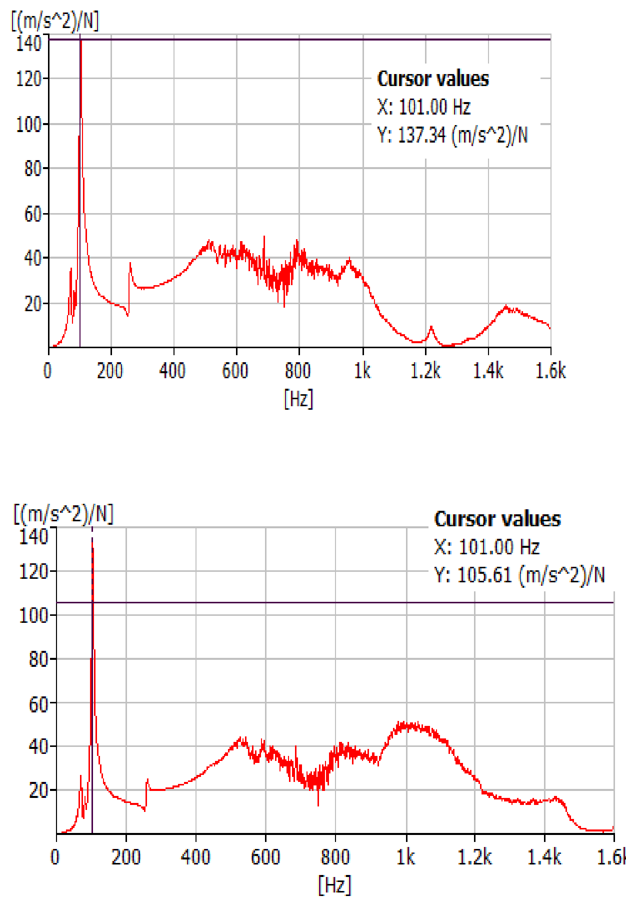


Figure 8: The Spectrum of AA6061 Plate at Rotational Speed (S) 500 r.p.m and Travers Speed (F) 10 mm/min

4. **For S500 F15**

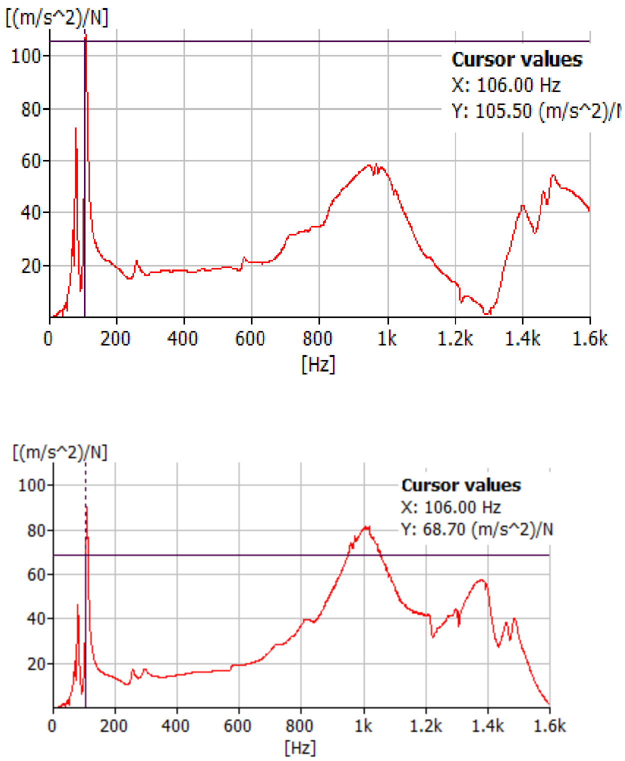
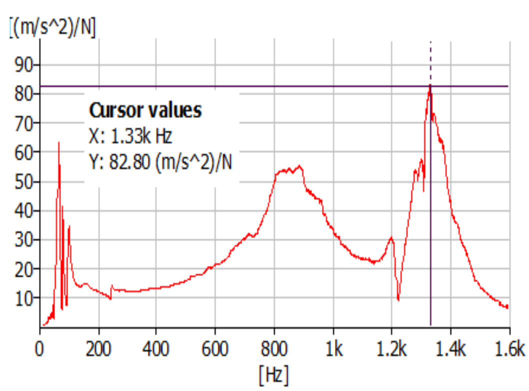


Figure 9: The Spectrum of AA6061 Plate at Rotational Speed (S) 500 r.p.m and Travers Speed (F) 15 mm/min

5. **For S800 F5**



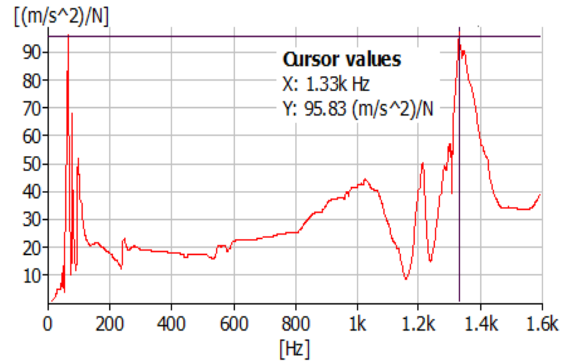


Figure 10: The Spectrum of AA6061 Plate at Rotational Speed (S) 800 r.p.m and Travers Speed (F) 5 mm/min

6. **For S800 F10**

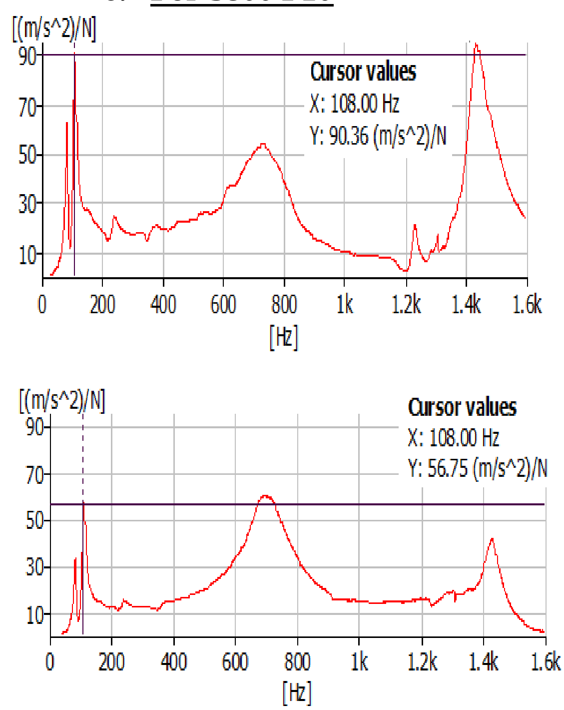
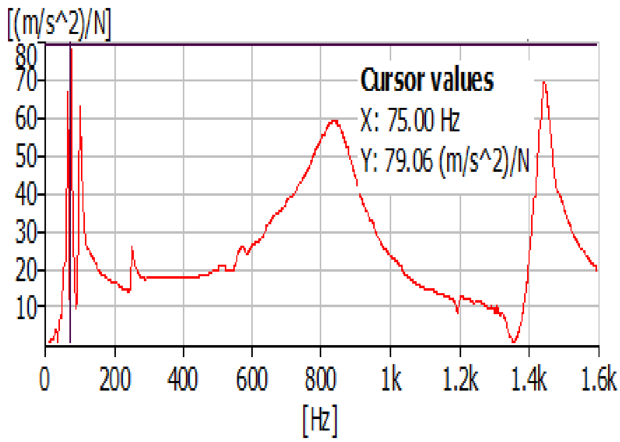


Figure 11: The Spectrum of AA6061 Plate at Rotational Speed (S) 800 r.p.m and Travers Speed (F) 10 mm/min

7. **For S800 F15**



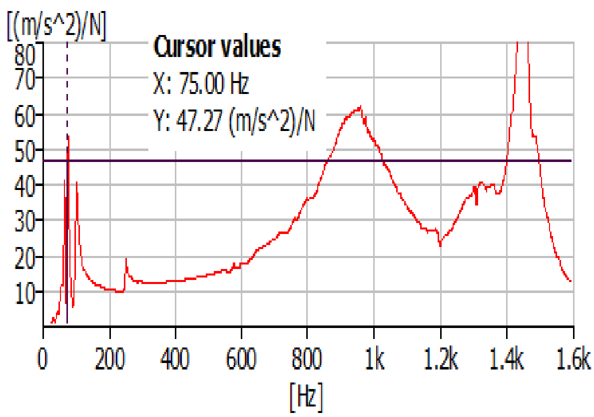
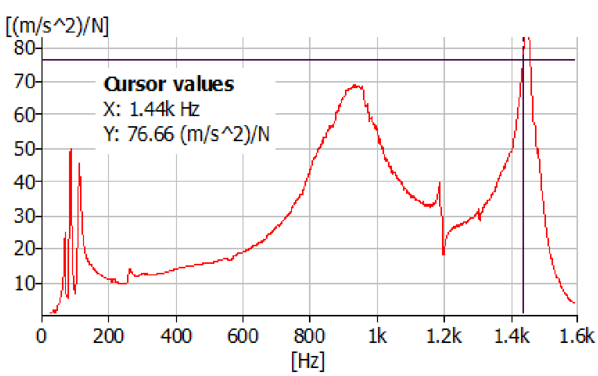


Figure 12: The Spectrum of AA6061 Plate at Rotational Speed (S) 800 r.p.m and Travers Speed (F) 15 mm/min

8. **For S1000 F5**



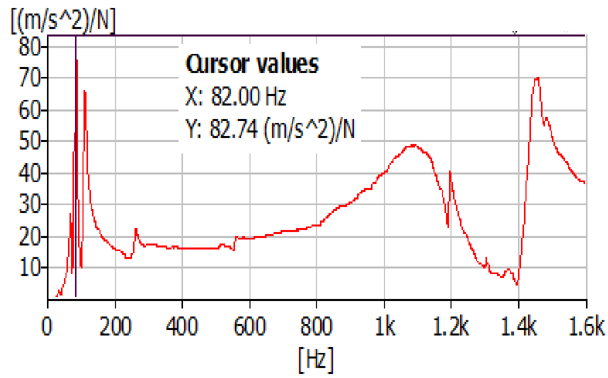
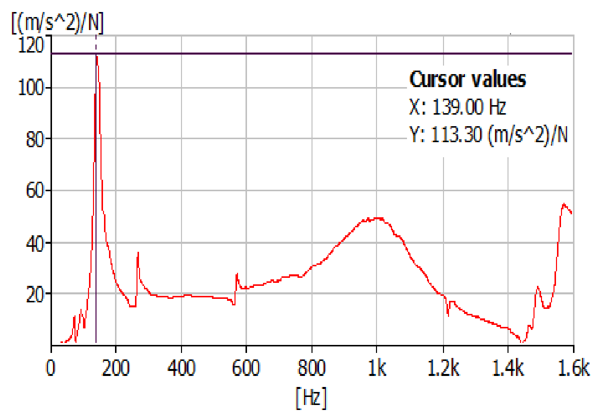


Figure 13: The Spectrum of AA6061 Plate at Rotational Speed (S) 1000 r.p.m and Travers Speed (F) 5 mm/min

9. **For S1000 F10**



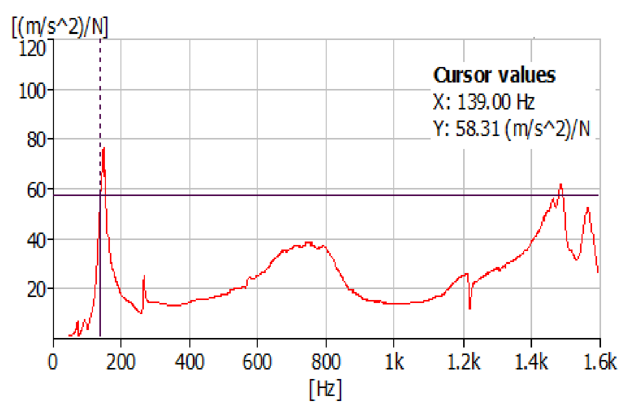
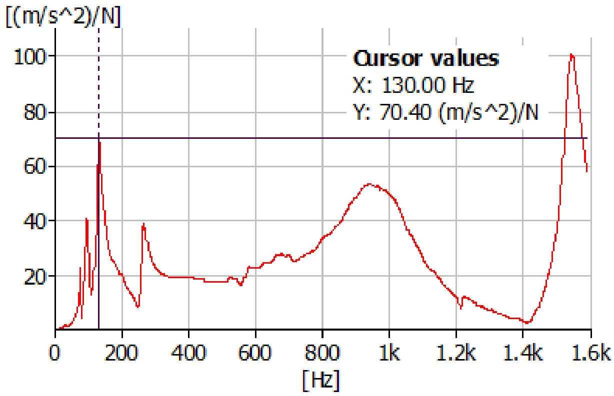


Figure 14: The Spectrum of AA6061Plate at Rotational Speed

(S) 1000 r.p.m and Travers Speed (F) 10 mm/min

10. <u>For S1000 F15</u>



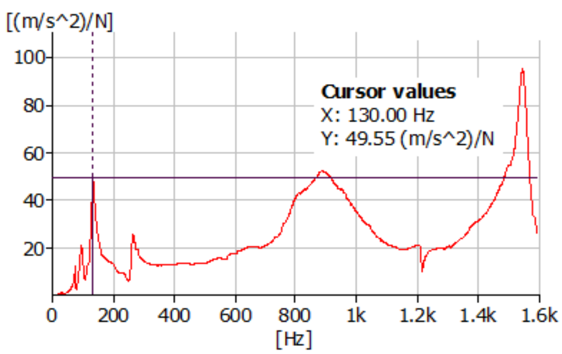


Figure 15: The Spectrum of AA6061 Plate at Rotational Speed (S) 1000 r.p.m and Travers Speed (F) 15 mm/min

CONCLUSION

The analysis of the dynamic test measurements gave a high accurate information about the AA6061 aluminum alloy at different working conditions. The analysis of the spectrums appeared that;

1. The impact force increasing with increasing in traverse and rotational speeds as shown in Figure 16.

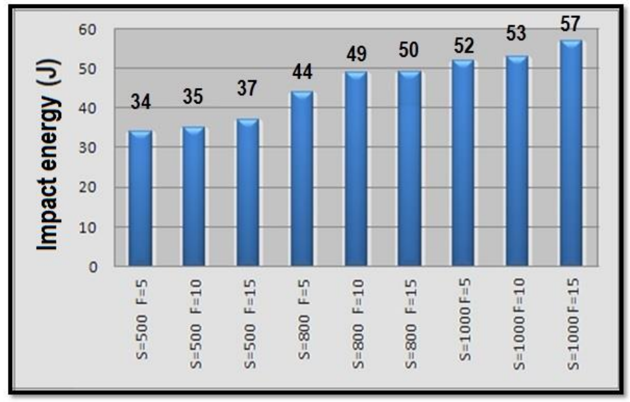


Figure 16: The Average Impact Energy in Jules for AA6061 FSP with Several Rotation and Traverse Speeds.

2. The impact force of AA6061 base material is 30J. That mean the AA6161 FSP impact force is greater than the impact force of the base material.
3. The natural frequency (ω) and damping ratio (ξ) of the AA6061 aluminum alloy decrease with increasing the rotational speed as shown in Table 2.

Table 2. Natural Frequency and Damping Ration of A6061 alloy at Different Rotational and Travers Speeds.

Conditions	Natural frequency ω_n (Hz)	Damping ξ (%)	Average ω(Hz)	Average ξ(%)
	128	3.87	131	3.89
	131	3.69		
	134	4.1		
S=500 rpm F=5 mm/min	91	2.55	92	2.74
	92	2.61		
	92	3.06		
S=500 rpm F=10 mm/min	101	4.23	103	3.48
	103	3.14		
	105	3.06		
S=500 rpm F=15 mm/min	107	3.74	109	3.31
	109	2.98		
	110	3.2		
S=800 rpm F=5 mm/min	78	1.83	79	1.94
	79	1.92		
	79	2.06		
S=800 rpm F=10 mm/min	81	3.98	82	3.94
	82	3.94		
	82	3.89		
S=800 rpm F=15 mm/min	75	2.49	75	2.49
S=1000 rpm F=5 mm/min	68	4.53	69	3.37
	69	2.82		
	69	2.75		
S=1000 rpm F=10 mm/min	139	6.86	145	6.31
	148	6.01		
	148	6.06		
S=1000 rpm F=15 mm/min	75	2.13	75	2.09
	75	2.13		
	75	2.02		

4. The natural frequency (ω) and damping ratio (ξ) of the AA6061 aluminum alloy decrease with increasing the traverse speed even the rotational speed increased as shown in Table 3.
5. The AA6061 aluminum alloy gave a good performance at up normal working conditions and this performance make it usefully used in multi applications.

Table 3. Average Natural Frequencies and Damping Ration of A6061 alloy at Different Rotational and Travers Speeds.

F	F=5		F=10		F=15	
S	ω(Hz)	ξ(%)	ω(Hz)	ξ(%)	ω(Hz)	ξ(%)
S=500	92	2.74	103	3.48	109	3.31
S=800	79	1.94	82	3.94	75	2.49
S=1000	69	3.37	145	6.31	75	2.09

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