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LOCKHEED MARTIN ENERGY RESEARCH CORPORATION  
FOR THE UNITED STATES  
DEPARTMENT OF ENERGY

ORNL-27 (3-96)

C/ORNL94-0272

ORNL/M--6073

CRADA Final Report  
for  
CRADA Number ORNL94-0272

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**INTERMETALLIC BLADES FOR  
FABRIC CUTTING**

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Lockheed Martin Energy Research Corporation  
for the  
U.S. Department of Energy  
under contract DE-AC05-96OR22464**

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## **Abstract**

This report describes the evaluation of nickel- and iron-aluminide blades for cutting fabric as opposed to conventional steel blades. The aluminides were selected as blade material because of their extremely high work-hardening rate and the possibility of forming aluminum oxide on the surface to further enhance the wear resistance. Unlike steel blades, they do not require heat treating to become strong. A testing facility using an Eastman cutter was designed and built at the Oak Ridge National Laboratory (ORNL) for testing of blades. Denim fabric supplied by Levi Strauss was used as. For lack of sufficient fabric, heavy paper was also used. Extensive testing revealed that there were several issues in getting the true comparison between various blades. The most important issue was the consistent sharpening of the blade edge. With all of the effort and precautions, identical edges could not be put on the blades of all the different materials. The second issue was the limited availability of fabric to evaluate the end-of-life limit for the blade edges.

Two nickel- and three iron-aluminide compositions were evaluated. Under test conditions, the iron-aluminide alloy (PM-60), based on FeAl, was found to outperform other aluminides and the steel blade. Based on the data presented in this report, we recommend that additional testing be carried out on both the steel and aluminide blades to determine the limit at which they require resharpener. Additional testing should be of sufficient duration to determine the number of times each blade can be sharpened prior to its replacement. However, the recommended testing needs to be conducted on blades for which the identical cutting edges and sharpening are incorporated. We further recommend that if the iron-aluminide blade is truly superior, a cost analysis be performed to determine its commercial feasibility. The best aluminide blades should be tested by commercial textile companies.

A patent was filed on the application of iron aluminides as cutting blades. Throughout this program, there were interactions between ORNL and Eastman Cutting Room Sales Corporation and (TC)<sup>2</sup> and Craig Fong at Lawrence Berkeley Laboratory (Berkeley, California). Other company visits were also made during the program. A white paper for testing of cutting blades was also submitted to AMTEX (see Appendix A).

## **CRADA Objectives**

This report is only a small part of the large Cooperative Research and Development Agreement (CRADA) with Amtex. The objective of this specific part of the CRADA was to evaluate the feasibility of using aluminides as blades for cutting fabric with the exception of significantly improved performance as opposed to steel blades.

## **Meeting Objectives**

All objectives of the CRADA were met. Specifically, a facility using an Eastman cutter was designed and built at ORNL for comparative testing of blades. Two nickel- and three iron-aluminide compositions were evaluated. Many blades were fabricated from the selected aluminides and tested.

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Research sponsored by the U.S. Department of Energy, Office of Energy Research, Energy Research Laboratory Technology Research Program, under contract DE-AC05-96OR22464 with Lockheed Martin Energy Research Corporation.

## CRADA Benefit to DOE

The nickel and iron aluminides were developed at ORNL through Department of Energy (DOE) funding. This CRADA provided the opportunity of evaluating the aluminides for fabric cutting applications. Without this CRADA, this application would not have been examined. The results of this CRADA have further established that the aluminides developed by DOE have broader applications than structural materials. It is these broader-based applications that help commercial manufacturers market advanced material, and this CRADA provided that benefit to DOE.

## Technical Discussion

### Introduction

Nickel and iron aluminides were evaluated as two candidate materials for fabric cutting applications. Unlike conventional alloys which have a disordered structure, nickel and iron aluminides have ordered structures. The aluminides are also known as intermetallic compounds. An intermetallic compound can be defined as an ordered alloy phase formed between two metallic elements, where an alloy phase is ordered if two or more sublattices are required to describe its atomic structure. These materials have very a high work-hardening rate (Table 1) as opposed to disordered alloys such as carbon and stainless steels. The aluminides can also form  $Al_2O_3$  on the surface by a simple heat treatment in air. The high work-hardening rate and the characteristic of  $Al_2O_3$  formation could possibly increase the cutting performance through increased wear resistance. Also, with every sharpening step, the aluminides will become more resistant to dulling through the increased work hardening. All of the considerations described above resulted in the evaluation of nickel- and iron-aluminide blades for fabric and paper cutting.

Table 1. Work-hardening rate<sup>a</sup> of polycrystals<sup>b</sup> (at axial strain of 0.1)

Material	Work-hardening rate (normalized with respect to the shear modulus, $G$ )	Reference
NiAl	$G/15 - G/38$	Dymek et al. (1992)
FeAl+	$G/7$	Baker and Nagpal (1993)
Zr <sub>3</sub> Al	$G/10$	Schulson (1984)
Ni <sub>3</sub> Al	$G/12$	Weih's et al. (1987)
Al <sub>3</sub> Sc	$G/15$	Schneibel and George (1990)
Al <sub>66</sub> Mn <sub>6</sub> V <sub>5</sub> Ti <sub>23</sub>	$G/15$	Zhang et al. (1990)
Al <sub>67</sub> Ni <sub>8</sub> Ti <sub>25</sub>	$G/19$	Turner et al. (1989)
Low-carbon steel	$\approx G/50$	U.S. Steel (1964)
301 Stainless steel	$G/40$	Brickner and Defilippi (1977)
Cu, Al, and Ni	$G/30 - G/40$	Feltham and Meakin (1957)
Cu <sub>3</sub> Au, Ni <sub>3</sub> Mn, and Ni <sub>3</sub> Fe	$G/23 - G/38$	Schulson (1984)

<sup>a</sup>For the intermetallics generally obtained from compression tests at room temperature.

<sup>b</sup>Furnace cooled after annealing.

### Blade Preparation

Blades were fabricated from three different aluminides [ $\text{Fe}_3\text{Al}$  (FA-129),  $\text{FeAl}$  (PM-60), and  $\text{Ni}_3\text{Al}$  (IC-221W)]. The nominal compositions of these alloys are given in Table 2.

Table 2. Composition of aluminides used for cutting-blade studies

Element	Alloy, weight percent		
	$\text{Fe}_3\text{Al}$ (FA-129)	$\text{FeAl}$ (PM-60)	$\text{Ni}_3\text{Al}$ (IC-221W)
Fe	77.66	73.45	--
Al	15.90	26.0	8.0
Cr	5.50	--	7.70
Mo	--	0.42	1.50
Nb	1.0	--	--
Zr	--	0.1	3.0
C	0.05	0.03	--
B	--	--	0.003
Ni	--	--	79.80

The  $\text{Fe}_3\text{Al}$  alloy was prepared by extrusion of powder in a mild steel can. The extrusion was carried out at  $1100^\circ\text{C}$ . The extruded bar was hot rolled to knife dimensions at  $650^\circ\text{C}$  and flattened at  $1000^\circ\text{C}$  for 1 h. Some of the sheet for additional blades was also prepared by extrusion of solid cast ingot without an ingot followed by rolling at  $650^\circ\text{C}$  and flattening at  $1000^\circ\text{C}$ . The  $\text{FeAl}$  alloy was also prepared from extrusion of powder in a mild steel can at  $1100^\circ\text{C}$ . The extruded bar was hot rolled at  $1000^\circ\text{C}$  to the final thickness and flattened at  $1000^\circ\text{C}$  prior to blade fabrication.

The  $\text{Ni}_3\text{Al}$ -based alloy, IC-221W, was also prepared by extrusion of powder in a mild steel can at  $1150^\circ\text{C}$ . The extruded bar was cold rolled with intermediate anneals at  $1100^\circ\text{C}$  to the final sheet thickness. The sheet was flattened at  $1000^\circ\text{C}$  prior to blade fabrication.

Two types of blades were machined from these materials. The first type was of the shape needed to fit a Gerber cutting machine, and the second to fit the Eastman cutting machine. The  $\text{Fe}_3\text{Al}$  and  $\text{Ni}_3\text{Al}$  Gerber blades were supplied to Richard Schwartz at the Los Alamos National Laboratory for evaluation. The Eastman blades were evaluated at the Oak Ridge National Laboratory (ORNL) using a test facility that was designed and built at ORNL. This is described in the next section. An Eastman blade is shown in Fig. 1.

### Blade Testing Facility at ORNL

The blade testing facility at ORNL is shown in Fig. 2(a,b). The test facility consisted of cutter acceleration apparatus [Fig. 3(a)], base track assembly [Fig. 3(b)], and cutting track assembly [Fig. 3(c)]. The details of the cutting force calculations are shown in Appendix B.



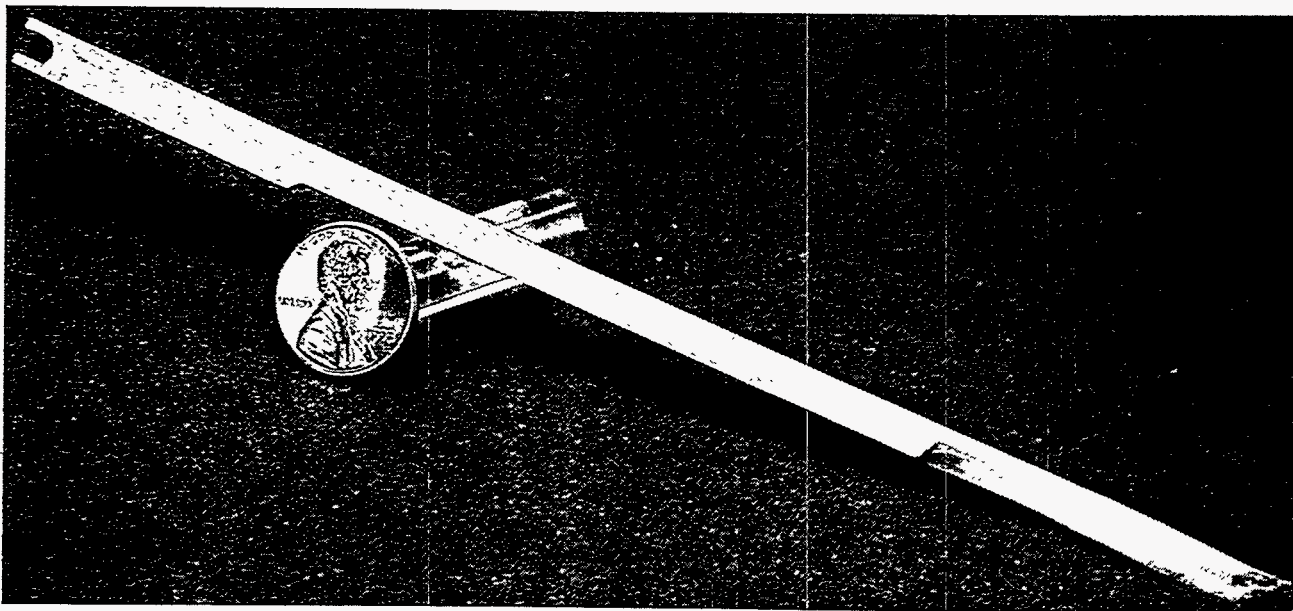


Fig. 1. Eastman blade.

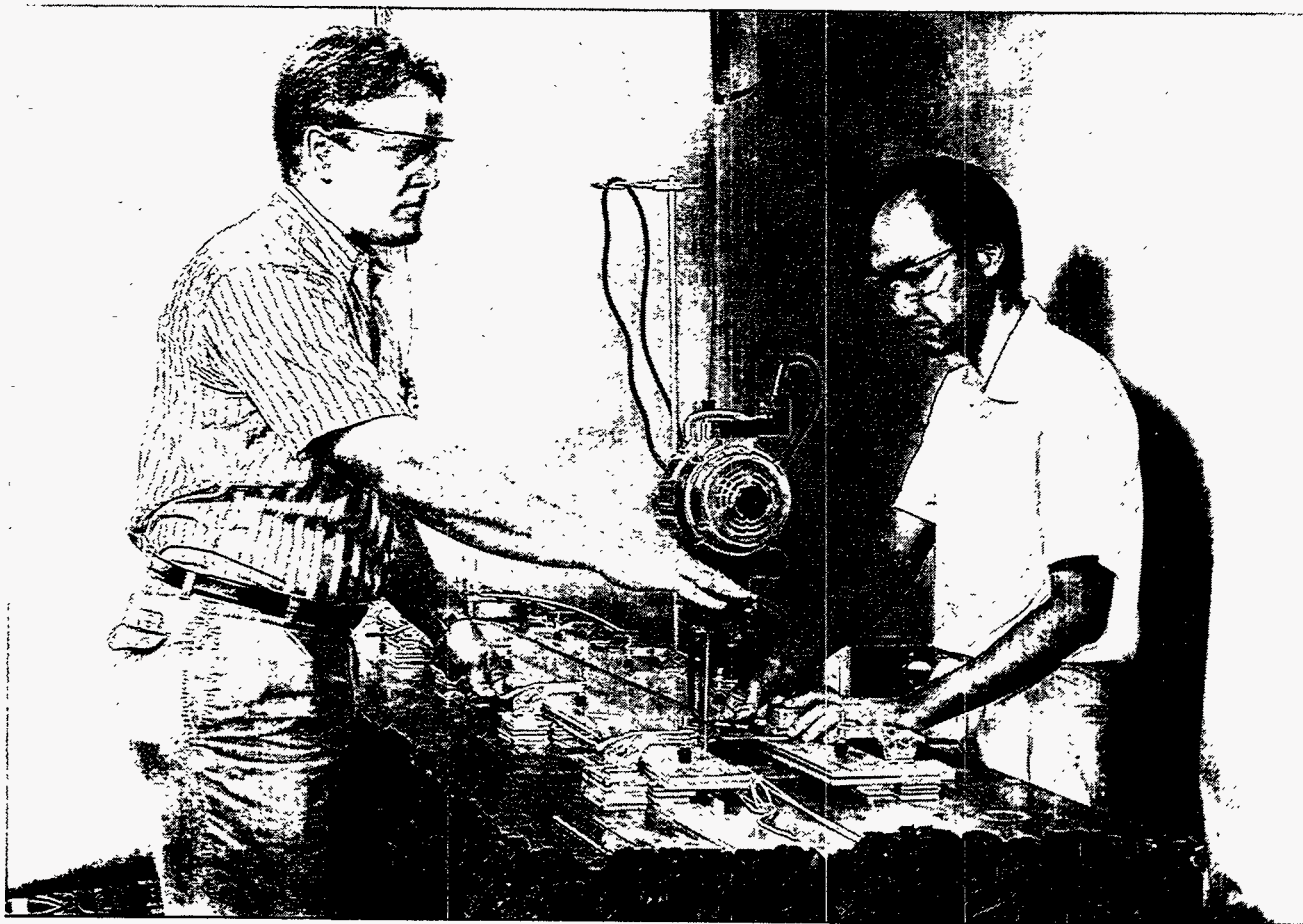


Fig. 2(a). Blade testing facility at the Oak Ridge National Laboratory.



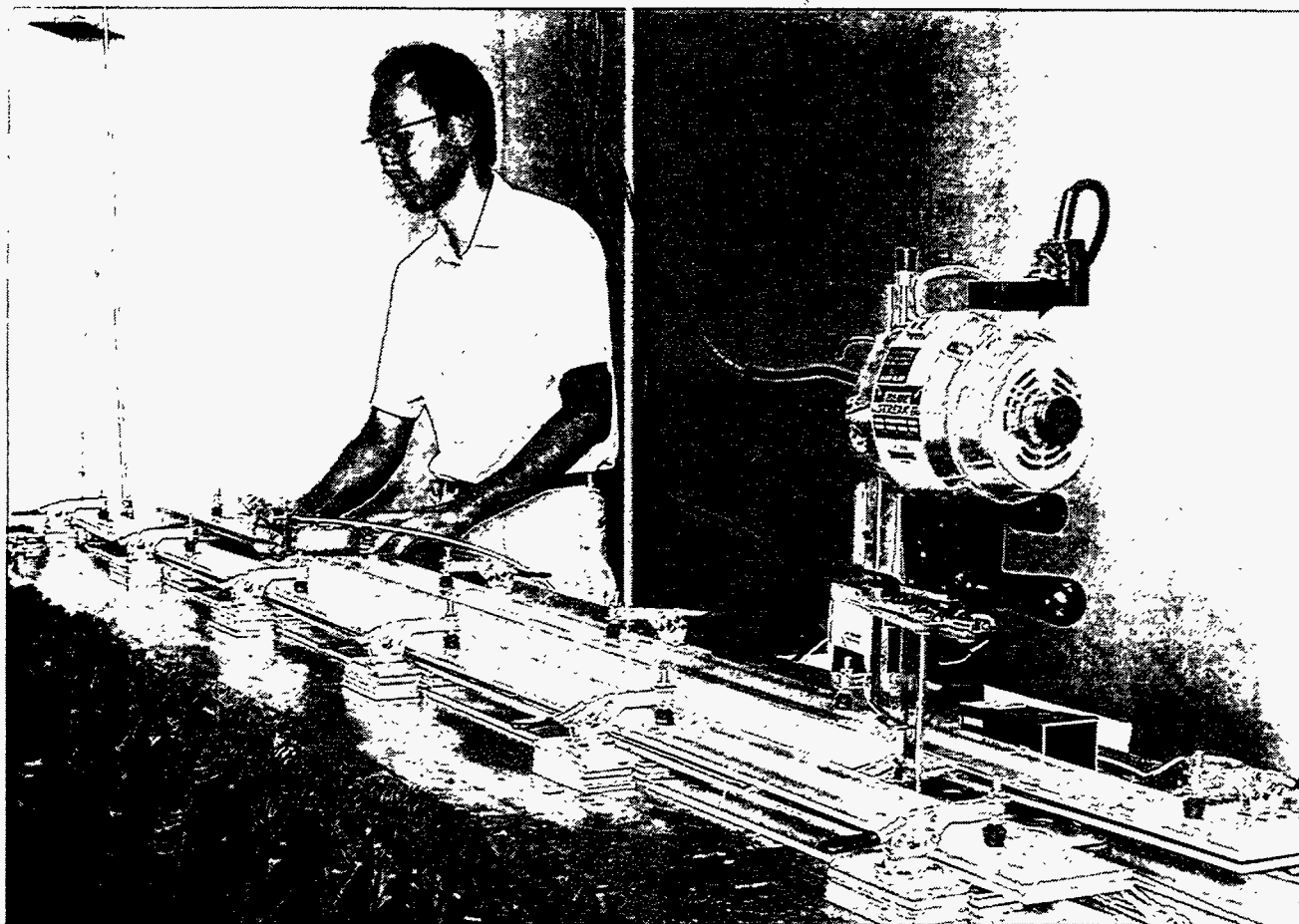


Fig. 2(b). Another view of the blade testing facility at the Oak Ridge National Laboratory.

During the test, in order to provide a constant force to advance the blade through a stack of fabric, the Eastman machine was pulled by a drop weight to translate the knife through the fabric along the cutting track. Additional rollers have been mounted on the cutting machine to reduce the friction against the track and to smooth the machine's movement. An electronic timer mounted on the aluminum track was used to measure the cut time. Before each cutting test, one needs to fasten a cable suspending the drop weight to the front side of Eastman machine's base plate, hook the back side of the base plate to a fixed bolt, lay the fabric, reset the timer, and clamp each lateral side of the fabric stack firmly between two plates. Once the cutting machine has been turned on and released from the hook, it will cut through the fabric stack. Parameters recorded are cut time, drop weight, and cut length.

## Results

### Comparative Results on Three Aluminides

Initial testing was carried out to compare the performance of the three different aluminides. In all cases, denim supplied by Levi Strauss and Company (Knoxville, Tennessee) was used. Before testing, each blade was sharpened with a new Eastman medium belt grit. The cutting edges of the blades were also examined using scanning electron microscopy. Before each cutting experiment, the Eastman machine was pulled by a five pound of drop weight to move it along the track without any fabric. The purpose of this step was to

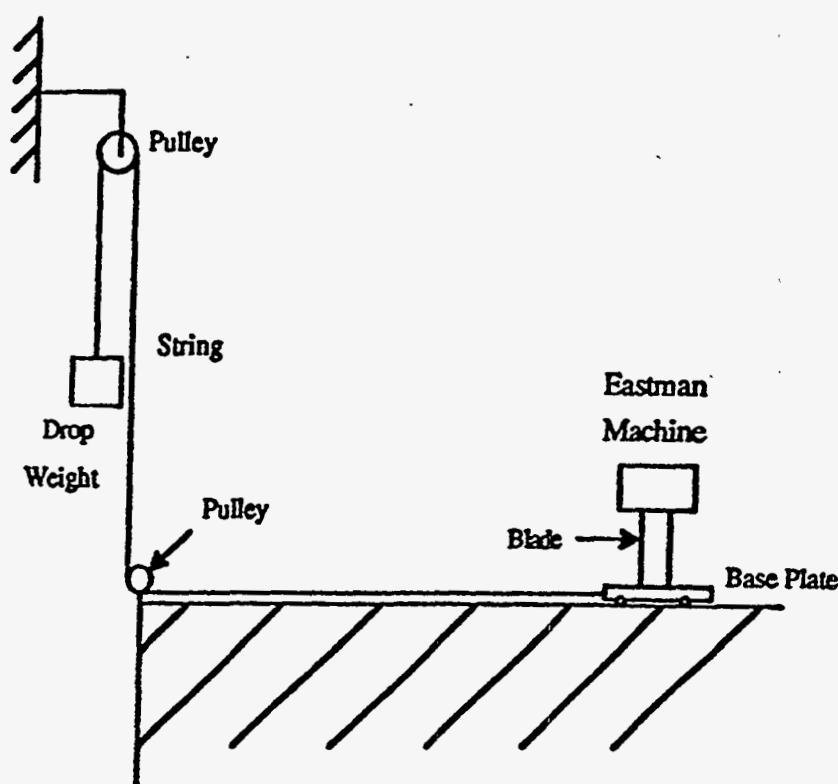


Fig. 3(a). Cutter acceleration apparatus.

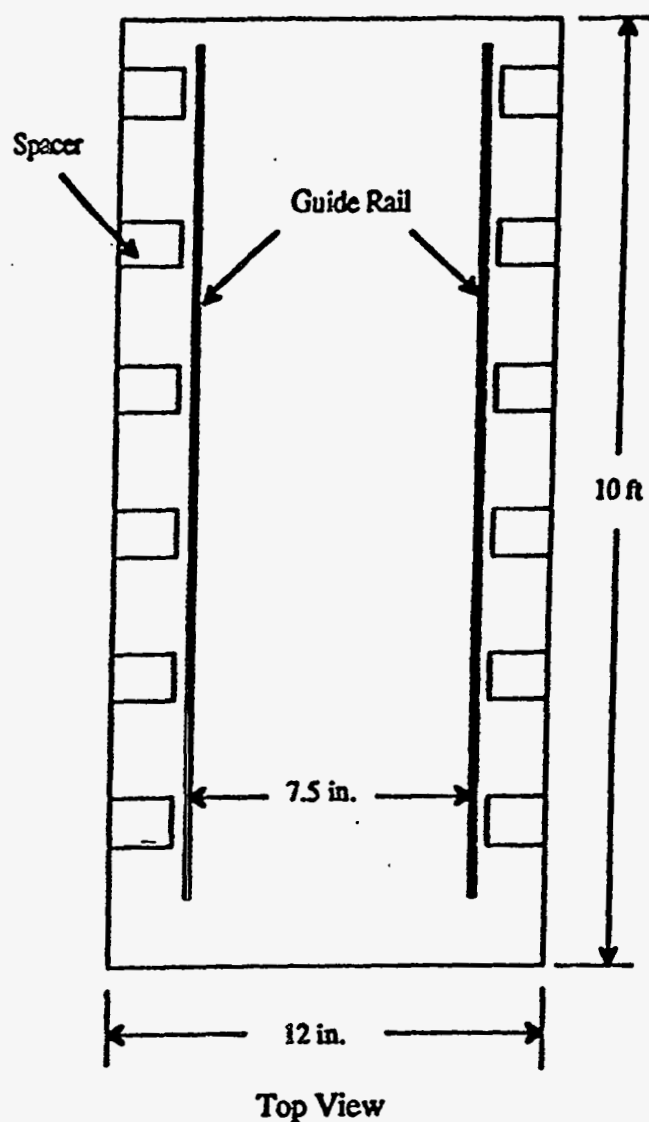


Fig. 3(b). Base track assembly

calibrate the system as well as evaluate the friction between the cutting machine and the track. In all cases, it took 1.95 to 2.05 s for the machine to travel 5 ft.

The cutting test results for the three intermetallic blades, with five pounds of drop weight and eight plies of denim, are given in Tables 3, 4, and 5. In these tables, average velocity, velocity per ply, cutting force (the force exerted onto fabric by the cutting knife), and force per ply were calculated from the measured data (cut time and distance). Refer to the appendix for details of the calculated results. The performance of three intermetallic blades was about the same. After cutting 60 ft of eight-ply denim (480 ft single ply), the blades were still performing well, no degradation of cutting speed. The comparisons of the cutting speed, cutting force, and cut time are shown in Figs. 4, 5, and 6, respectively. As can be seen from these figures, the cutting speed, cutting force, and cut time all remain essentially constant over the total cut length suggesting that no blade degradation had occurred.

Table 3. Cutting test results of FA-129 blade

Cut no.	Drop weight (lb)	Measured time (s)	Measured distance (in.)	Average velocity (in./s)	Ply count	Velocity per ply (in./s-ply)	Cutting force (lb)	Force per ply (lb)
1	5	6.25	60.5	9.680	8	77.44	2.343	0.293
2	5	6.49	60.5	9.322	8	74.58	2.363	0.295
3	5	6.80	60.5	8.897	8	71.18	2.386	0.298
4	5	6.91	60.5	8.755	8	70.04	2.393	0.299
5	5	7.00	60.5	8.643	8	69.14	2.399	0.300
6	5	6.37	60.5	9.498	8	75.98	2.353	0.294
7	5	6.89	60.5	8.781	8	70.25	2.392	0.299
8	5	7.01	60.5	8.631	8	69.04	2.399	0.300
9	5	6.30	60.5	9.603	8	76.83	2.347	0.293
10	5	6.61	60.5	9.153	8	73.22	2.372	0.297

Table 4. Cutting test results of FeAl blade

Cut no.	Drop weight (lb)	Measured time (s)	Measured distance (in.)	Average velocity (in./s)	Ply count	Velocity per ply (in./s-ply)	Cutting force (lb)	Force per ply (lb)
1	5	6.00	60.5	10.083	8	80.667	2.346	0.293
2	5	7.46	60.5	8.110	8	64.879	2.451	0.306
3	5	7.38	60.5	8.198	8	65.583	2.447	0.306
4	5	7.38	60.5	8.198	8	65.583	2.447	0.306
5	5	7.39	60.5	8.187	8	65.494	2.447	0.306
6	5	7.10	60.5	8.521	8	68.169	2.431	0.304
7	5	7.36	60.5	8.220	8	65.761	2.446	0.306
8	5	7.77	60.5	7.786	8	62.291	2.466	0.306
9	5	7.99	60.5	7.572	8	60.576	2.474	0.309
10	5	6.89	60.5	8.781	8	70.247	2.418	0.302
11	5	7.98	60.5	7.581	8	60.652	2.475	0.309
12	5	6.68	60.5	9.057	8	72.455	2.403	0.300

Table 5. Cutting test results of IC-221W blade

Cut no.	Drop weight (lb)	Measured time (s)	Measured distance (in.)	Average velocity (in./s)	Ply count	Velocity per ply (in./s-ply)	Cutting force (lb)	Force per ply (lb)
1	5	8.90	60.5	6.798	8	54.382	2.481	0.310
2	5	7.78	60.5	7.776	8	62.211	2.440	0.305
3	5	7.68	60.5	7.878	8	63.021	2.435	0.304
4	5	7.16	60.5	8.450	8	67.598	2.408	0.301
5	5	7.23	60.5	8.368	8	66.943	2.412	0.302
6	5	7.14	60.5	8.473	8	67.787	2.407	0.301
7	5	6.82	60.5	8.871	8	70.968	2.387	0.298
8	5	6.27	60.5	9.649	8	77.193	2.345	0.293
9	5	6.72	60.5	9.003	8	72.024	2.380	0.298
10	5	6.79	60.5	8.910	8	71.281	2.385	0.298
11	5	7.03	60.5	8.606	8	68.848	2.400	0.300
12	5	6.77	60.5	8.936	8	71.492	2.383	0.298

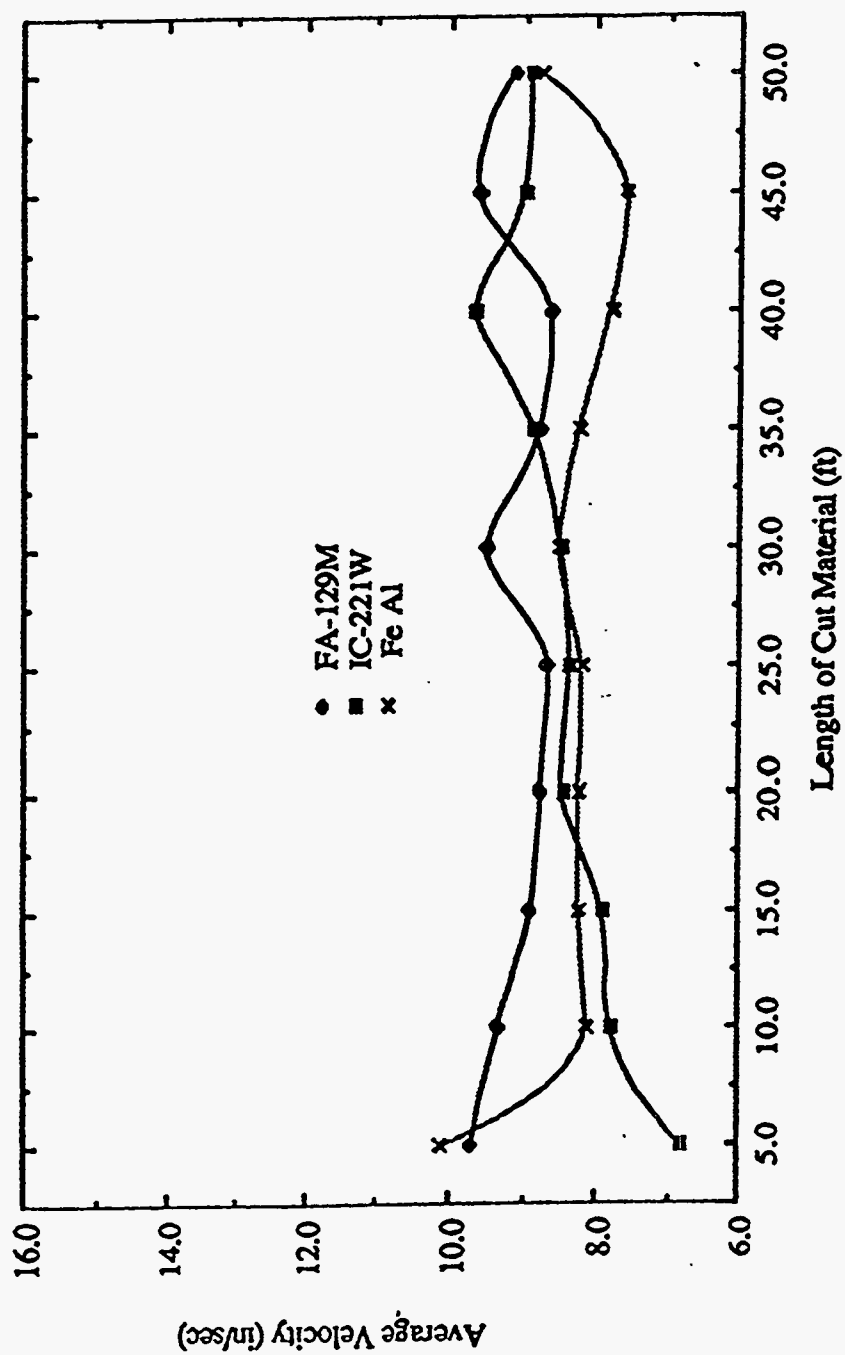


Fig. 4. Comparison of the cutting speed.



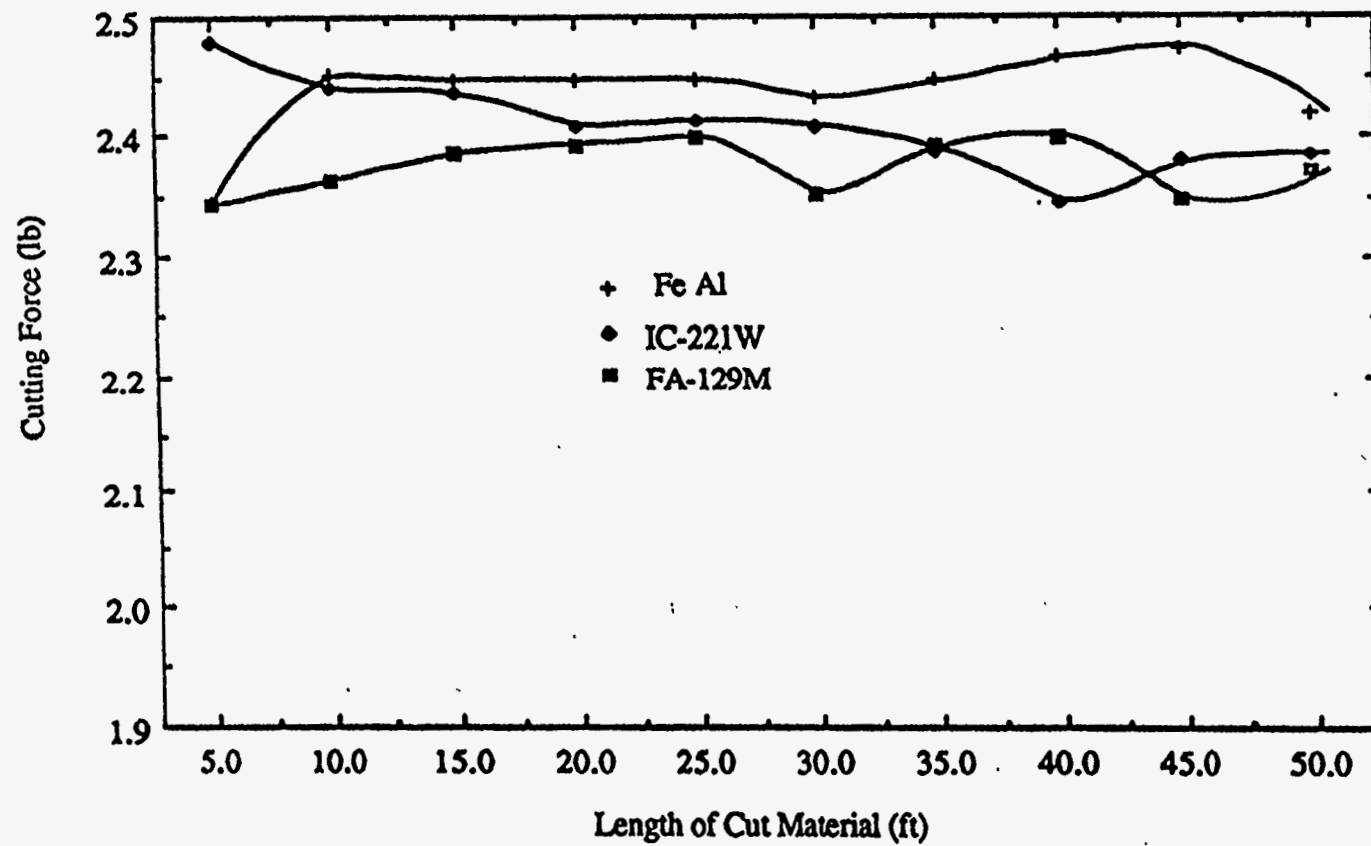


Fig. 5. Comparison of the cutting force.

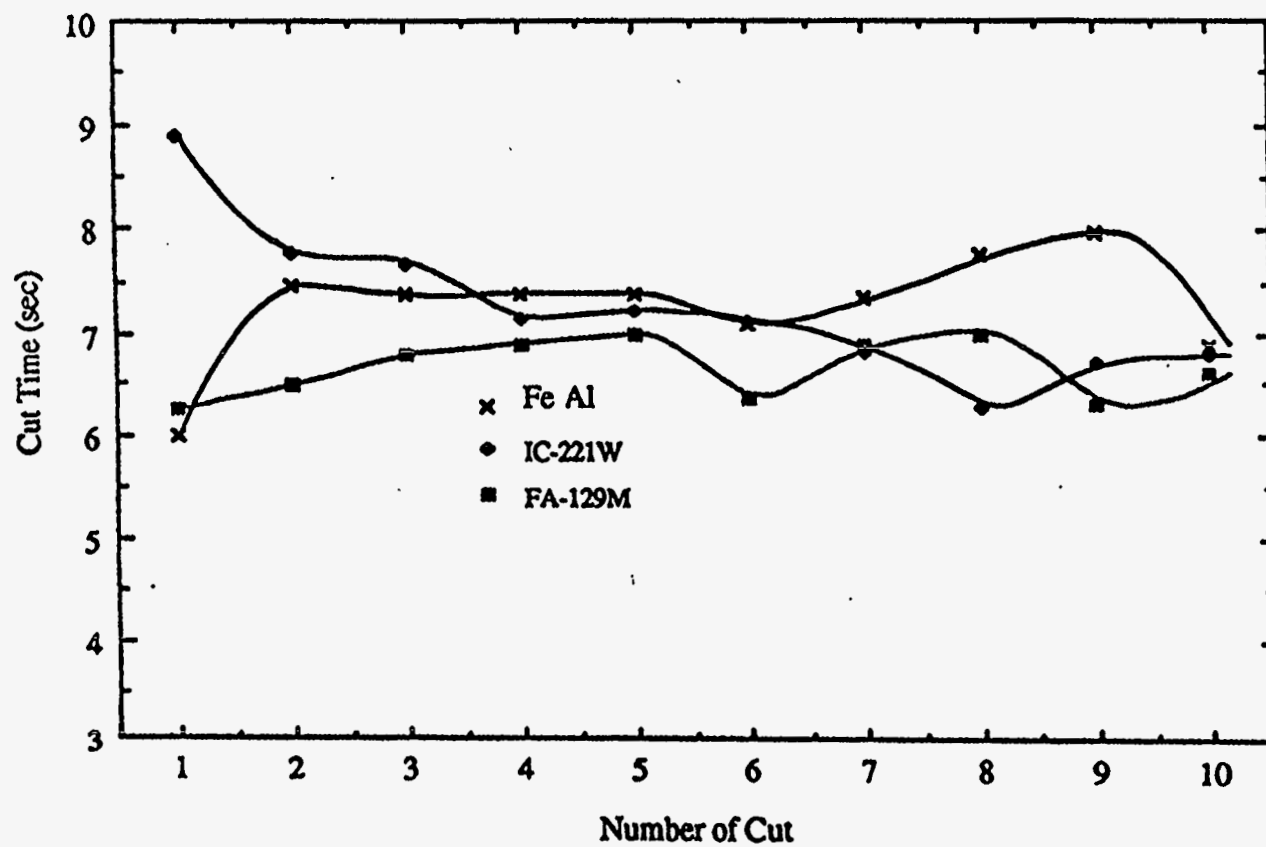


Fig. 6. Comparison of the cut time.

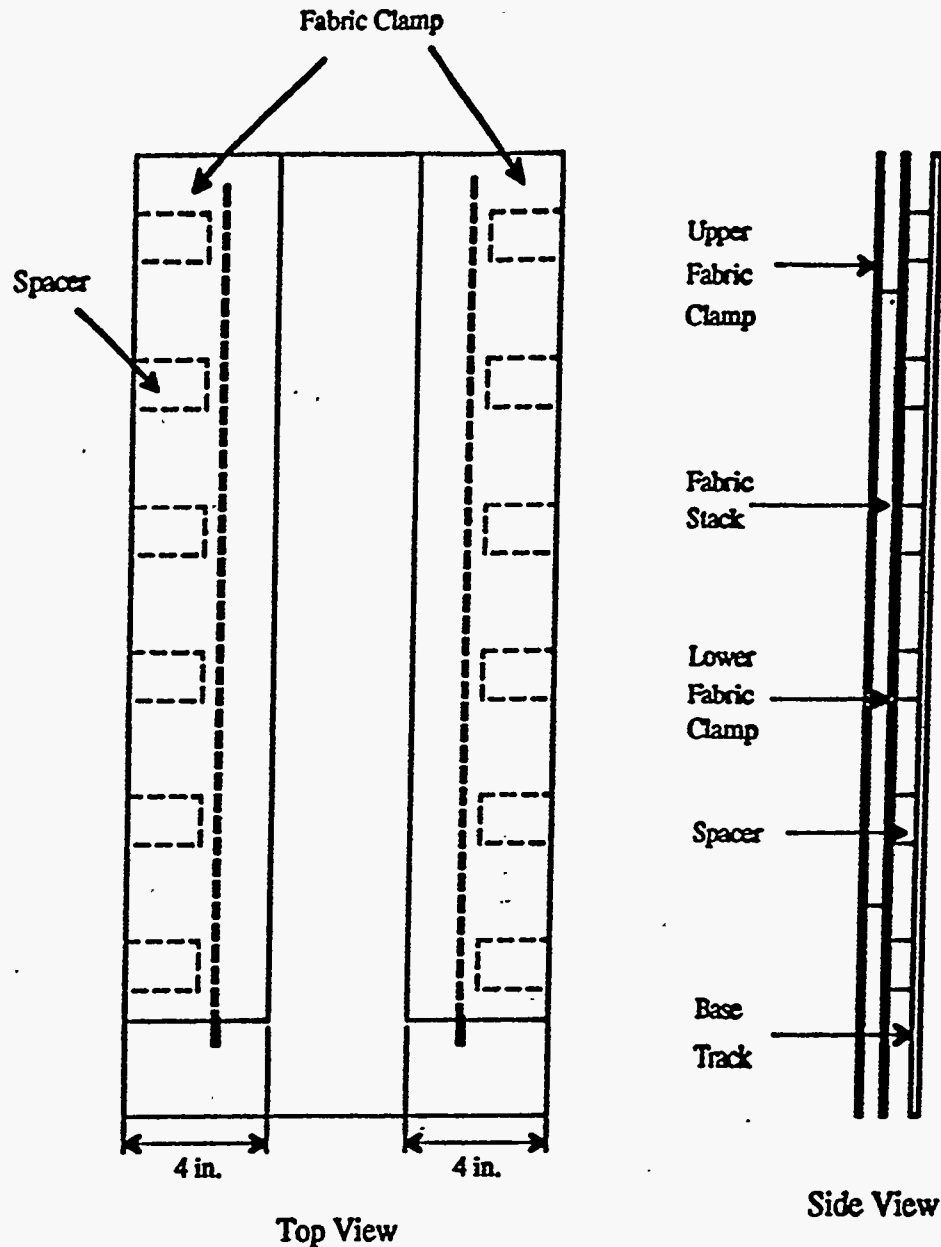


Fig. 3(c). Cutting track assembly.

#### Comparison of Aluminides with Conventional Blades

In this testing sequence, it was decided to expand the  $\text{Ni}_3\text{Al}$  to include an additional alloy, IC-50, and an additional  $\text{Fe}_3\text{Al}$  alloy known as FAS-II. Compositions of these two alloys are given in Table 6. The IC-50 alloy was processed identically to IC-221W. The FAS-II alloy used a water-atomized powder rather than gas atomized for all other cases. The idea of water-atomized powder was to explore the effects of  $\text{Al}_2\text{O}_3$  particles that get incorporated in the alloy during the water atomization process. It was expected that the  $\text{Al}_2\text{O}_3$  particles would provide additional wear resistance. Water-atomized powder of FAS-II was also hot extruded at  $1100^\circ\text{C}$  in a steel can and rolled to  $650^\circ\text{C}$  followed by flattening at  $1000^\circ\text{C}$ .

Table 6. Compositions of IC-50 and FAS-II

Element	Alloy (weight percent)	
	IC-50	FAS-II
Fe	--	81.87
Al	11.3	15.9
Cr	--	2.20
Zr	0.6	--
B	0.02	0.01
O	00	0.25
N	--	0.004
Ni	88.08	--

All of the blades were fabricated at ORNL and sharpened by hand on a sharpening machine in the metal shop. The Eastman steel blades were commercially produced and sharpened using their sharpening methods. Unfortunately, attempts to sharpen the ORNL blades at Eastman were unsuccessful. Eventually, tests were run using an Eastman blade that had been dulled and then resharpened at ORNL using the same method as used with the experimental blades.

For each run, the data collected was the time that each blade took to cut through a known length of fabric. Runs were repeated for up to 25 runs for each blade. These times were then compared to view any trends that might have occurred. As the incremental times began to increase, it was assumed that the blades were getting less sharp. From this logic, it was assumed that a blade that maintained a constant run time for a long period is more durable and less susceptible to losing its sharp cutting edge than a blade that exhibited increasing run times.

The standard test that was used comprised of running each of the blades a number of times using the same conditions (weight, material, amount of material, and number of manual sharpenings). Most of the tests used multilayered denim fabric or heavy duty paper in long strips. However, runs were also attempted using short multilayered denim strips lined up next to each other. Also, once the blades began to show obvious signs of wear and loss of sharpness, the manual sharpener was sometimes used to evaluate the effects of resharpening.

In an attempt to find the best force (weight) to use, a test was run using the Eastman and FAS-II blades. Each blade was used to cut eight-ply denim fabric. The force was gradually increased between each run. The rate at which each blade cut through the fabric increased as the force was increased, but the plots can be seen leveling off showing that there was a point where no matter how much force was added, the speed of the cut would not increase (see Fig. 7). Due to the limited amount of material available, this exact point was never found, but a general idea for suitable forces to use in the main tests was found.

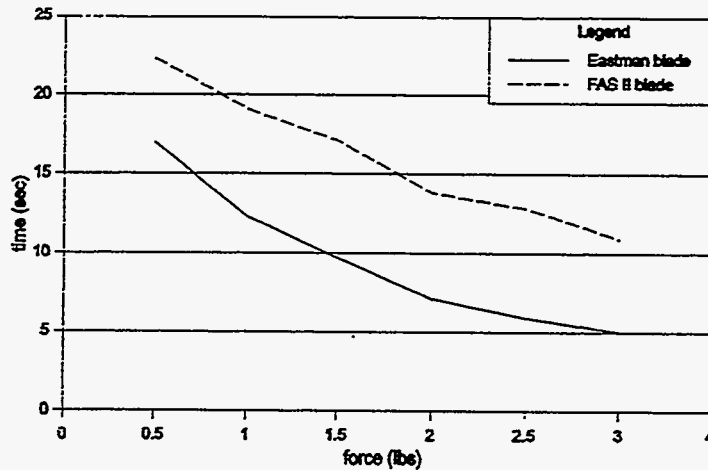


Fig. 7. Time versus force plots for Eastman steel blade and FAS-II blade.

An extensive duration test was performed with the Eastman blade to first find the limitations of the blades used in industry. Eight-ply denim was used with a constant weight of 2 lb. It was found that after 25 runs, the speed of the cuts remained unchanged (see Fig. 8). The amount of fabric actually cut was approximately equivalent to 1000 ft of 1-ply denim. No serious signs of loss of sharpness were found.

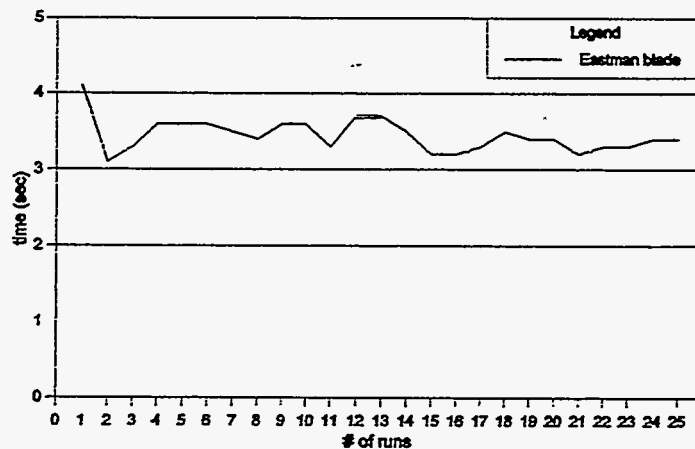


Fig. 8. Time to cut versus the number of runs for Eastman blade using a force of 2 lb.

In hopes of better evaluating the durability of the blades, an interrupted cut test was executed. The Eastman and FAS-II blades were compared. Eleven runs were made for each blade using ten pieces of eight-ply denim which were lined up down the track. A constant weight of 1.5 lb was used. It was shown that the Eastman blade slightly outperformed the FAS-II experimental blade [i.e., the Eastman blade was faster during each run (see Fig. 9)]. Neither blade showed any significant signs of becoming less sharp. More material was needed to make any solid conclusions.

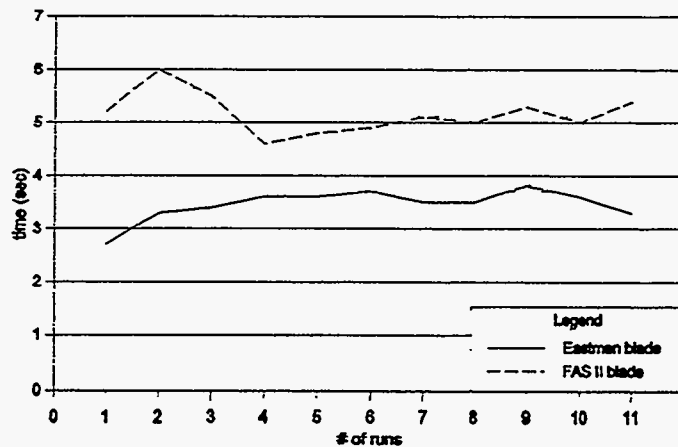


Fig. 9. Comparison of interrupted cut results for Eastman blade and FAS-II alloy.

Three of the four experimental blades (IC-50, FAS-II, and PM-60) were compared in hopes of determining which was the most durable and effective of the new blades. Ten runs were completed for each blade using two-ply heavy duty paper and a constant weight of 3.5 lb. It was shown that the times were all relatively similar for the first run, but then times for the IC-50 and FAS-II blades increase while the PM-60 run times remained unchanged. The PM-60 blade greatly outperformed the other two blades (see Fig. 10).

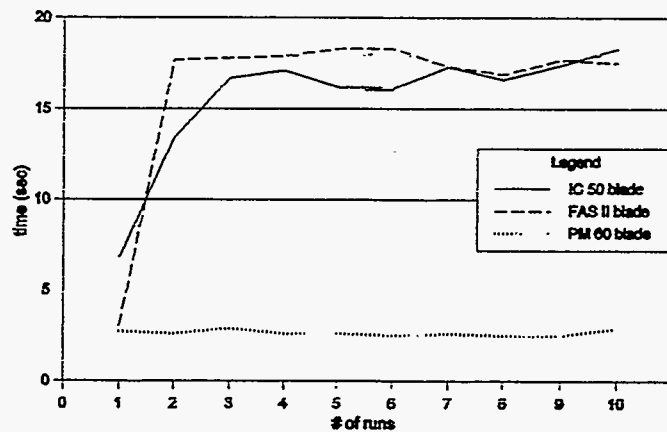


Fig. 10. Comparison of relative performance of IC-50, FAS-II, and PM-60.

A second duration test was performed again using the Eastman blade. This time, two-ply heavy duty paper was used to try to dull the blade, which was previously unaffected by the denim. This test was designed to determine the combination of material, amount of material, and force that would have an obvious effect on the blades in less than 20 runs, thus minimizing use of material and time. Twenty runs were completed using a constant 3-lb force. No decrease of time or loss of sharpness were seen. In fact, the blade seemed to be getting faster (see Fig. 11). Again, more material was needed to view any long-term effects.



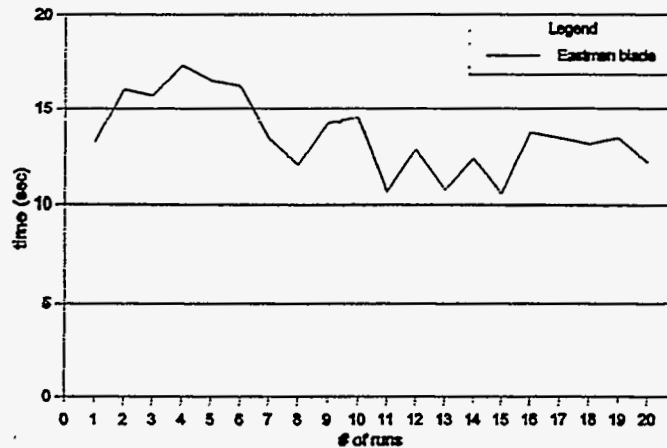


Fig. 11. Second Eastman duration test to determine the limit for dulling the Eastman blade.

A final test was run in order to make an overall comparison of all of the blades. Each of the blades, including the Eastman blade, were resharpened in the metal shop at ORNL. Then they were all again sharpened using the built-in manual sharpener on the cutting machine. Each blade was sharpened five times in this manner before cutting the material. Two-ply heavy duty paper was used with a constant 6-lb force. Ten runs were completed with each blade. Despite minor fluctuations in the times, the performance of each blade remained relatively similar (see Fig. 12). Each blade exhibited a tendency to become less sharp (the times per run increased). However, when comparing the time for the first run with the time for the final run for each blade, it was possible to rank the materials. It is not clear for this limited test whether this trend is real.

### Discussion

After viewing the first duration test (Fig. 8) and seeing that the performance was unaffected by the extreme number of runs, an alternative material and/or force that would speed up the process and show the deterioration of the blades was sought. The limited amount of materials and time made this a necessity. Heavy paper was chosen as an alternative material since it was thought to be more abrasive than denim and would act to dull the blades more rapidly.

The test using interrupted cut was not very successful when viewed in the laboratory. On occasions, the small strips of fabric would slip as the blade was cutting them, causing the times to increase.

After looking at the test that was run only with the three experimental blades (Fig. 10), it was suspected that the original sharpness of the blades was not uniform, since in previous practice tests that were run to test the apparatus, the PM-60 blade performed more closely to the others. This observation suggests that the difference between materials was not as great as indicated in Fig. 10. Another indication that the blades were not sharpened equally was that the Eastman blades consistently outperformed the experimental ones. This does not seem possible when the material used to make the experimental blades had been shown to be more wear resistant than common steel when tested under other conditions.

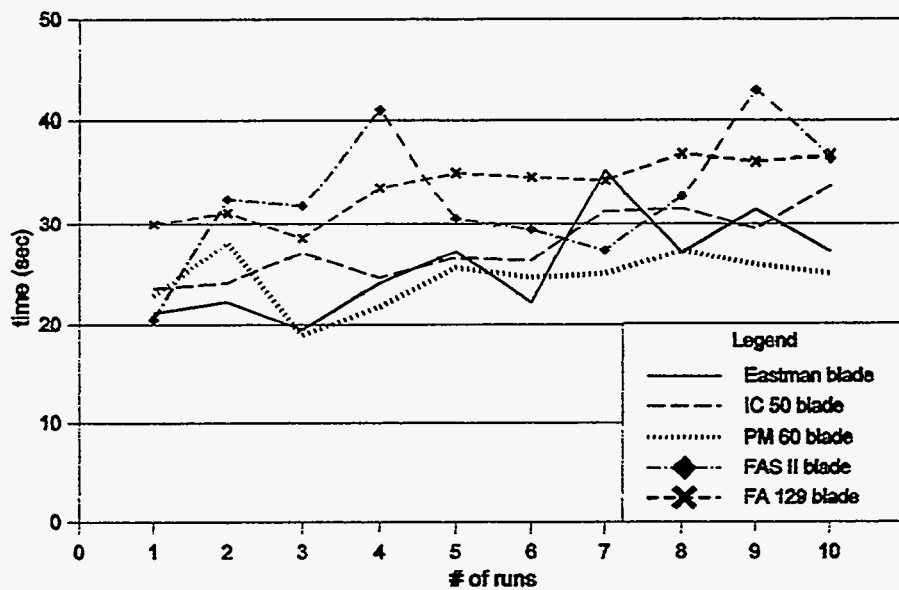


Fig. 12. Comparison of aluminide blade with Eastman blade under identical conditions.

A further attempt to damage the Eastman blade occurred in the second duration test, but was yet again unsuccessful (Fig. 11). It seemed that the correct combination of amount of material and force had still not been reached to efficiently slow the blade.

For the final test, each of the blades were resharpened in hopes of starting each of the blades with the same sharp edge. This resharpening was somewhat successful because the measured data fell in a much smaller range than in previous tests. In fact, the PM-60 blade appeared to outperform even the Eastman blade, which had been superior in all previous tests. Again, the lack of materials and time inhibited further testing. Even 6 lb of force pushing the blades through two-ply heavy duty paper did not affect the blades sufficiently. More runs could have been conducted, and a final conclusion could have been made.

All in all, a completely accurate way of equally sharpening the blades was not found. The Eastman blades were sharper than the ones prepared in the metal shop. Even when the Eastman blade was prepared the same way as the others, there were some discrepancies. A cutting material that provided enough wear on the blades in a reasonable amount of time was also not found. Realistic amounts of denim and heavy duty paper seemed to have only minimal effect on the performance of the blades. However, the final test provided the best control of the parameters, including sharpness. All of the blades were getting less sharp, and they all seemed to be performing in a close range with less variability. In addition, even with a limited number of runs, it appears to be possible to rank the various materials in terms of durability, with the PM-60 blade performing the best, even better than the Eastman blade. Further tests would be necessary to confirm this conclusion.

#### Recommendations

First, proper testing conditions must be established. The material (and amount of it) along with the correct force to apply need to be established. Inquiry on how much fabric a standard blade cuts before it wears enough to need to be replaced should be made directly to the industry. The answer may reveal that different kinds of testing need to take place.

The maximum amount of fabric that was cut during testing was only 1000 ft. If the commercial length of fabric cut is significantly more, then it would take a very long period of time and a large amount of materials to properly test the blades. An alternative might be to use an extremely heavy duty material or an extremely large force to push the blades in order to establish an accelerated test procedure.

Second, all of the blades need to begin testing with the same amount of sharpness. The most effective way to do this would be to have all of the blades sharpened by Eastman using their sharpening device. However, this was attempted unsuccessfully in the past. Possibly another attempt could be made with Eastman or perhaps another company in the industry. An alternative to this would be to find another effective way to consistently sharpen all of the blades. The method used in the machine shop at ORNL improved the consistency of the blades, but still was not effective enough. Maybe an independent company could do the sharpening.

A third step that should be taken is to run the final test again (results shown in Fig. 12) using the same parameters, but with more runs. This was the most successful test, and there was evidence that some sort of conclusion could be made. The PM-60 blade looked as though it outperformed all of the others. This result might be confirmed with further testing. If it is possible that the blades be resharpened in a more accurate manner at ORNL's metal shop, this would be helpful to ensure the correctness of the results.

Another area to be considered is the usefulness of the experimental product. It is possible that there is no need in industry to improve the cutting blades. Even if the experimental blades outperform the standard steel ones, they (the experimental blades) might cost more to produce and sharpen. The production costs of each blade should be compared. Also, a survey of companies in the industry could be conducted to find out if there is any real interest or need for new blades.

Ultimately, the best way to test the experimental blades would be to use them in the industry and see how they perform. While this would be very difficult to set up, it is an idea worth considering.

### **Report of Inventions**

There were no inventions developed under this agreement.

### **Commercialization Possibilities**

This is possible, but without the commercial source for material, even the best aluminide will not find applications.

### **Plans for Future Collaboration**

No plans have been made for future collaboration.

### **Conclusions**

Nickel- and iron-aluminide blades were evaluated for cutting fabric as opposed to conventional steel blades. The aluminides were selected as blade material because of their extremely high work-hardening rate and the possibility of forming aluminum oxide on the surface to further enhance the wear resistance. Unlike steel blades, they do not require heat

treating to become strong. A testing facility using an Eastman cutter was designed and built at the Oak Ridge National Laboratory (ORNL) for testing of blades. Denim fabric supplied by Levi Strauss was used as. For lack of sufficient fabric, heavy paper was also used. Extensive testing revealed that there were several issues in getting the true comparison between various blades. The most important issue was the consistent sharpening of the blade edge. With all of the effort and precautions, identical edges could not be put on the blades of all the different materials. The second issue was the limited availability of fabric to evaluate the end-of-life limit for the blade edges.

From the testing of two nickel and three iron-aluminide compositions, the following was possible:

1. The FeAl-based iron-aluminide alloy (PM-60) was found to outperform other aluminides and the steel blade. However, additional testing is required to establish the extent of superior performance as opposed to the conventional steel blade. Once the extent of the degree of superior performance is established, a cost analysis needs to be carried out to determine its commercial feasibility. The laboratory testing also needs to be supported by the commercial textile companies.
2. The testing facility using the Eastman cutter was designed and built at ORNL. This testing facility provided a consistent method for developing quantitative data for the evaluation of different blades. Without such a facility, only qualitative results could be obtained.
3. A commercial source for obtaining the FeAl-based iron-aluminide alloy (PM-60) was established. It was realized that without the commercial source for material, even the best aluminide will not find applications.

## APPENDIX A

# **WHITE PAPER SUBMITTED TO AMTEX FOR THE TESTING OF CUTTING BLADES**

by  
ORNL Cutting Blade Effort in the Materials Processing Group  
Craig A. Blue and Vinod K. Sikka

## **INTRODUCTION**

The major issue of concern when testing existing and newly developed cutting blades is that of performing objective tests that correlate to blade performance. To this point, a standard blade performance test method has not been put forward as clearly stated by Joe Off [1] and Jim Caldwell [2] of (TC)<sup>2</sup>. It is the purpose of this paper to put forward two possible bench mark blade test techniques. One technique would be for the had held EASTMAN type cutters and the second would be for the GERBER type table cutter.

The five factors outlined by Roy Stevenson [3], of Eastman Cutting Room Sales Corporation, which must be addressed when evaluating blade performance are as follows:

1. How keen an edge can the blade hold, with what bevel?
2. How long does the cutting edge last between sharpening?
3. How difficult is the blade to sharpen?
4. How many sharpening can the blade endure?
5. How hot does the blade get during cutting?

These factors outlined by Roy Stevenson will be addressed in the two test methods put forth in this paper. In regards to the cost of each type of blade or coating versus its performance and the overall likelihood of the blade being used by an individual customer, this will be depicted by specific needs of the customer and overall cost savings.

## **PROPOSED BENCH MARK BLADE TESTING TECHNIQUES**

### **GERBER Type Table Cutter**

The GERBERcutter will allow for the most objective test of the blade performance in an industrial setting due the fact that the modern GERBERcutter is a PC-based control unit. Therefore, the blade speed, fabric feed rate, fabric, and knife path traveled (fabric pattern) can all



be a constant from one test run to the next, thus eliminating the human factor. While visiting OSHKOSH B'GOSH, INC. in Columbia Kentucky, it was observed that they no longer used Gerber blades due to heating problem with the blade which resulted in deflection of the blade. This particular fabric cutting facility also uses only one type of blade for all of its cutting and the blade is typically sharpened every 100 inches of fabric automatically by the Gerber cutting head. The blades are changed every day, 20 hours, irrelevant of the condition of the blade. The twenty hour time limit of the Bohler type 047 cutting blade was extracted from experience and has been shown to minimize blade breakage and deflection. Also, it was stated by the Corporate Engineer, Cherita Caldwell [4], that a blade breaking, catastrophic failure, was much more favorable than deflection of the blade which can result in two hours of cutting material improperly. The typical cost of the Bohler blade is approximately nine dollars.

### Experimental Setup

- Designate a GERBERcutter at a company or purchase a used one, 50 - 70K, and locate it at one national laboratory for the testing of all the blades and coatings.

### Part 1

- Start with a designated material that is typically difficult to cut, for example, the 10 ply seat material used in the initial testing of the iron aluminide knife.

- Test all knives under the same conditions, for example, a blade speed of 3500 RPM, cutting table vacuum of 4.0 inches of mercury, and feed rate of 4 inches per second.

- Initially check all knives for:

- \* Bevel with a scanning electron microscope, nondestructive testing.
- \* Microhardness, nondestructive testing.

- Also, attach thermal couples to the back edge of the knives along the lengths to provide thermal histories.

- A given pattern can be obtained from OSHKOSH B'GOSH, INC. and down loaded for testing.

- Initially, do not sharpen the blades during cutting.

- Record the thermal histories and amperage of the motors running the blades in real time.
- Every 50 inches of cutting, stop the process and examine the bevel and microhardness of the blade. This would result in approximately 300 inches of material and six stops before the edge would be polished over for a standard blade and the initial iron aluminide blade if the test was continuous.

## Part 2

- After the initial testing outlined above, repeat the test recording all parameters but run the knives to 350 inches and examine the blades again. This would take into account continuous heating of the blade.

## Part 3

- Based on the above results, some preliminary conclusions on the blades performance could be obtained and in some cases, the material or coating may be altered. At this point, if the blades performed unsatisfactorily, destructive testing could be accomplished, metallography, to further understand the failure mechanisms.
- If the results from the above test were favorable, the test could be continued until the edge of the blade was polished over or other unfavorable occurrences, deflection of blade, which is a function of temperature, increase in motor amperage, etc.

## Part 4

- The blades would be tested in the GERBERcutter for ease of sharpening.
- The coated blades would not be able to be sharpened.
- The newly developed blades would be sharpened with the same stones utilized with the high speed steel blades and carbon steel blades and bevel and hardness checked as a function of thermal history and number of times sharpened.

## Part 5

- Upon satisfactory completion of all the above testing, certain blades could be chosen for extended field testing.
- After extended field testing at a given fabric cutting facility, the blades could be returned to a national laboratory for repeated testing as above and/or nondestructive and destructive evaluation.
- These tests take into account all the factors outlined by Roy Stevenson of Eastman Cutting Room Sales Corporation.

### EASTMAN Type Hand Held Cutters

The hand held cutter is sparingly used at OSHKOSH B'GOSH, INC. and only about twelve blades are consumed per year. Therefore, the testing of the hand held cutters is of little interest to them. Exposure to other companies would probably reveal the importance of the hand held cutter and more information on this is appreciated. The testing of the hand held cutter could be done in the exact fashion as the GERBERcutter unit. Simple manipulations could be made to the GERBERcutter to mount the hand held unit for cutting in a systematic way. It is realized that this does not simulate the motion and variations of a human operator but, it would seem to be the only means of extracting meaningful data. A Eastman type hand held cutter has been purchased this quarter and plans for modification have been made in order to be able to detect changes in the amperage due to the degradation of the blade. Also, plans for the installation of extensometers and thermocouples on the hand held unit have been made in order to measure deflection of the blade and temperature change. Preliminary tests with the hand held cutter should be completed with 1-2 weeks.

### CONCLUSION

Testing and evaluation techniques for cutting blades have been laid out that take into account the concerns of both the industry and national laboratories. With further communication between national laboratories and all the companies involved, this plan can be tailored to better approach all the concerns in a short period of time while producing meaningful results to enhance the performance of the cutting blades.

## REFERENCES

- [1] Discussions with Joe Off of (TC)<sup>2</sup>.
- [2] Discussions with Jim Caldwell of (TC)<sup>2</sup>.
- [3] Memo from Roy Stevenson of Eastman Cutting Room Sales Corporation to Craig Fong.
- [4] Discussion with Cherita Caldwell and Bobby Morrison of OSHKOSH B'GOSH during the visit to the company.

## FUNDS REQUESTED AND SCHEDULE

	<u>Cost</u>		Schedule (weeks from start)	
	<u>Capital</u>	<u>Operating</u>		
Task I. Procurement of GERBER *80K cutter, Ordering and Delivery			6-8 weeks	
A. Installation of GERBER Machine at ORNL	10K		10 weeks	
Task II. Modification of Eastman cutter, Addition of Sensors & Setup	10K		2 weeks	
Task III. Testing Tasks			A. Eastman	B. Gerber
1) Testing and Evaluation of ORNL Blades, SEM Microhardness, Elemental Analysis, etc.	25K		3 weeks	11 weeks
2) Testing and Evaluation of ANL Blades SEM Microhardness, Elemental Analysis, etc.	25K		4 weeks	12 weeks
3) Testing and Evaluation of LLNL Blades SEM Microhardness, Elemental Analysis, etc.	25K		5 weeks	13 weeks
4) Metallurgical Evaluation of Blades, Destructive Testing, Elemental Analysis, SEM, etc.	30K		6 weeks	14 weeks
5) Testing of Selected Blades at an Industrial Partner Extended Field Testing	30K		7 weeks	15 weeks
	Total	80K	-----	155K

\* Capital Equipment Funds Required

## APPENDIX B



## Calculating the Cutting Force

### 1 Acceleration

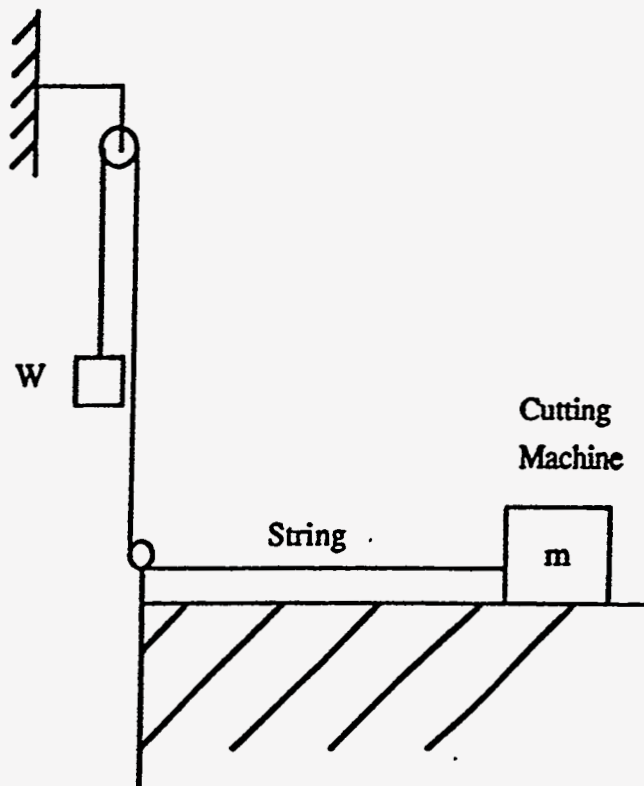


Figure 1.

If there is no friction force, from the free-body diagram (Figure 2), we can write

$$W g - T = W a \quad (\text{or } W g - W a = T) \quad (1)$$

$$T = m a \quad (2)$$

where  $T$  is the tension in cable,  $g$  is the gravity, and  $m$  is the mass of the cutting machine.

By substituting Equation (1) into (2), the acceleration of this system can be expressed as

$$a = \frac{Wg}{W + m} \quad (3)$$

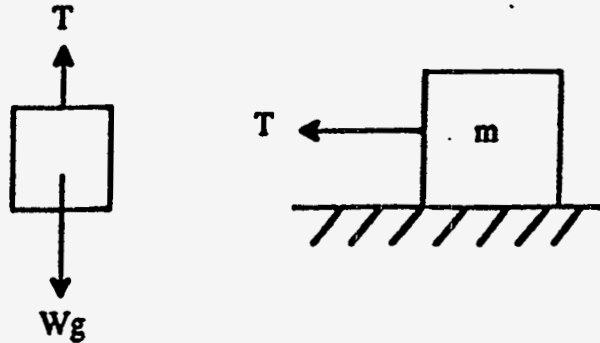


Figure 2. Free-Body Diagram

If the friction force being considered, from free-body diagram (Figure 3), we can express

$$T - f = m a \quad (4)$$

where  $f$  represents friction force. Substitution of Equation (1) into (4) results in

$$Wg - W a - f = m a \quad (5)$$

Thus, the acceleration can be expressed as

$$a = \frac{Wg - f}{W + m} \quad (6)$$

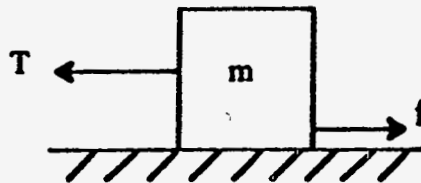


Figure 3. Free-Body Diagram

## 2 Determination of "a" by Experiment

"d", the machine's traveling distance, can be measured. "t", the time needed for machine to complete the travel, also can be measured. From the basic Physics, we have

$$d = \frac{1}{2} a t^2 \quad (7)$$

Once we find "d" and "t", the "a" can be calculated by

$$a = \frac{2d}{t^2} \quad (8)$$

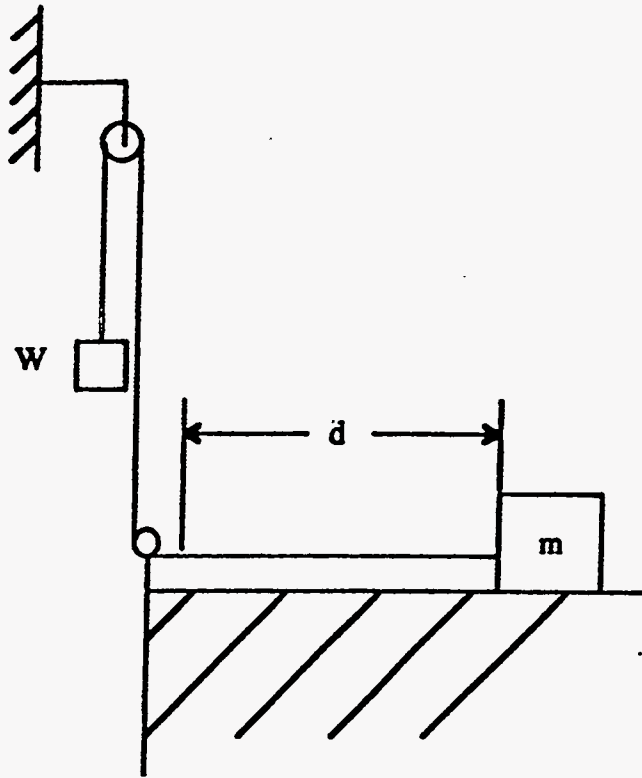


Figure 4.

### 3 Cutting Force

$F$  represents the cutting force, the force exerted onto fabric by the cutting knife. From free-body diagram (Figure 5), we have

$$T - F - f = m a_1 \quad (9)$$

where  $a_1$  is the acceleration of system when the fabric being cutting. By rearranging Equation (9), we have

$$T - f - m a_1 = F \quad (10)$$

We can find  $a_1$  by using the same method presented in the previous section.

By substituting Equation (4) into Equation (10), the cutting force,  $F$ , can be expressed as

$$F = m a - m a_1 \quad (11)$$

or

$$F = m (a - a_1) \quad (12)$$

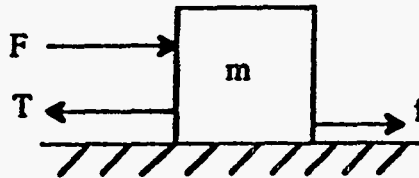


Figure 5.

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