SKI AND WAX TESTING

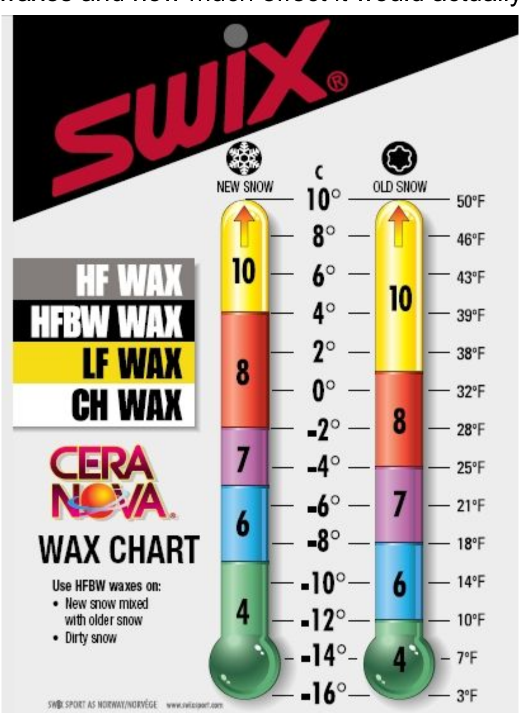
By Rick Budde and Adam Himes

Preface: Our technical paper titled ***High Resolution Friction Measurements of Cross Country Ski Bases on Snow*** *was recently published in Winter Sports Special Issue of Journal of Sports Engineering (Volume 20, Issue 4, December 2017).*
http://link.springer.com/article/10.1007/s12283-017-0230-5

That paper documents the full technical details of the test equipment and methods we developed to assemble a large database of test results comparing different waxes. This article describes how that data can be of everyday practical use by skiers. Additional information is also available on our website: *www.skitestguys.com*

It all started about five years ago when Adam Himes sent Rick Budde an email and asked, “Do you want to do a ski waxing experiment with me?”. In our day jobs as mechanical engineers, we develop test methods based on fundamental physics principles to measure things like friction. Here was an opportunity to apply engineering to skiing! How could I say no to a question like that?

We’ve all seen wax charts like this one. We wanted to know more precisely the difference between the waxes and how much effect it would actually have on our Birkie times.



The two of us, like most skiers, spend a lot of time waxing our skis and debating the merits of various waxes. The latest wax recommendations from the wax manufacturers or ski shops are eagerly awaited before big races. For all the attention skiers devote to the topic of wax, something is always conspicuously absent: there is no meaningful data available on how the various waxes actually perform!

In other words, we have no idea how much faster (or slower!) different waxes will be under different conditions.

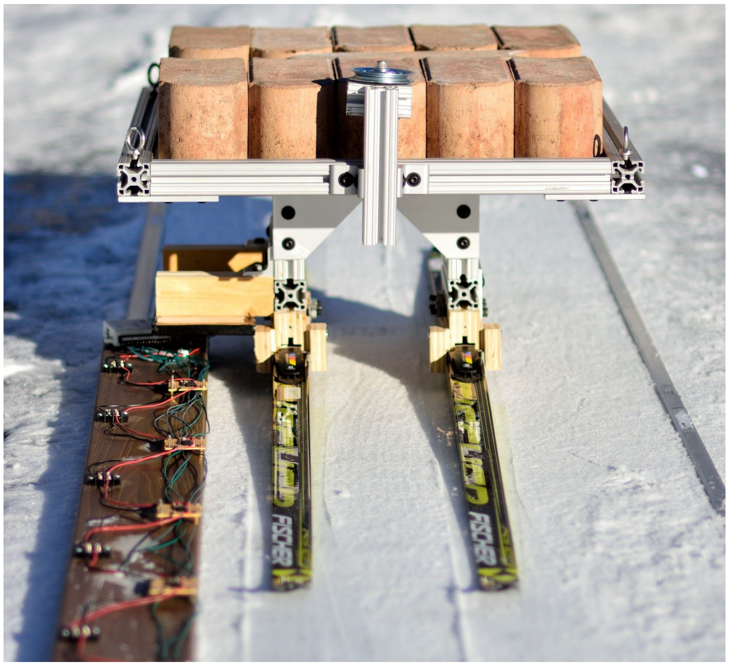
We searched the internet for information. We found many charts like the one above and some research papers in technical journals on the topic of snow friction but that information was not of much practical use to recreational skiers. So we decided to get some of our own data to create a wax performance reference guide that any skier could use to help them make more informed decisions regarding ski preparation. It sounded easy in the beginning but it took five years to put all the pieces together.

The first thing we tried is that old standby, the glide test. We assembled our quiver of skis for testing, got our tape measure, recorded our results, and analyzed the data. What did we get? Well, the usual semi-quantitative data about how much farther ski A with wax X glided relative to ski B with wax Y at temperature Z with such-and-such snow conditions on some particular hill. Hmm . . . useful, if you just need to just pick between a few of pair of skis on that day. But there are some issues. For starters, how do you translate a boot-length of glide distance to race time in the Birkie? And we found that repeatability is a problem when things like wind gusts, varying snow conditions, or the way the trail is groomed often confounded the results. We quickly realized this approach was not going to result in a comprehensive wax performance study spanning temperature and snow conditions.

We needed something much more rigorous that was rooted in fundamental physics. There are only four things that affect ski speed: propulsion from the skier, gravity, air resistance, and friction between ski and snow. We needed to accurately measure the coefficient of friction. If you know the coefficient of friction then you can start to compile a large database of test results and make meaningful comparisons over time, temperature, and snow conditions. You can then use some physics equations to make a pretty good estimate how much actual performance variation there will be while skiing.

We employed several different methods to get the coefficient of friction. We tried direct force measurements and we also tried to refine the glide distance test. There were two main issues that emerged: experimental repeatability, and speed dependence. Experimental repeatability refers to all the things that can cause differences in the results from one test to the next. Speed dependence means that the friction force changes with the speed of the ski. In short, we needed a very high level of precision that would account for the speed of the skis in the test.

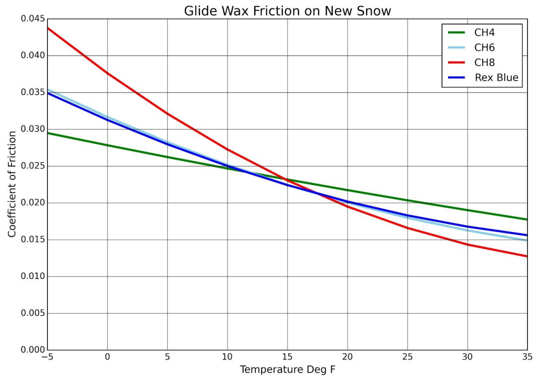
We ultimately ended up with the test system shown below. We attached skis to a test sled loaded with bricks with the correct weight for these skis (165 lbs). We ran the test sled down a very flat test track. The speed of the sled along the track was measured with a series of eight sensors. The test sled slows down slightly as it moves along the test track due to the friction of the ski on the snow. The rate at which the test sled slows down gives us our measurement of the coefficient of friction.

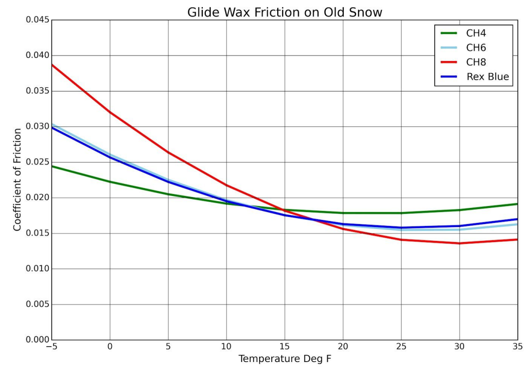


It’s well known that wax performance is sensitive to temperature, and that’s why the packages are labeled that way. But wax performance is also a function of factors like humidity, age of the snow, how well-packed the snow is, as well as the load profile (also called flex), and grind of the ski base. The changes due to these other factors can introduce a lot of measurement variation, something test engineers commonly call “noise”. By taking many repeated measurements, and comparing our test results against another ski prepared the same way every time (also called a “control” ski), we were able to significantly reduce the experimental noise.

This approach to measuring friction of skis on snow provided data at a higher level of precision than we were able to find in any published research. So, we decided to publish it in a technical journal. For those people interested in all aspects of the test hardware and analysis, the details are available online in ***High-resolution Friction Measurements of Cross-Country Ski Bases on Snow***, http://link.springer.com/article/10.1007/s12283-017-0230-5. Additional information and perspective is also available on our website: www.skitestguys.com and in a YouTube video linked into our website.

In the rest of this article we will concentrate on the test results we acquired to create the wax performance guide we initially wanted. The data presented below was gathered over a period of two years with nearly 1000 separate runs down the test track using a portion of the Swix line of CH waxes and Rex Blue. The charts below represent the average performance you could expect of these waxes as a function of temperature.





Let's talk about how to interpret these charts. The number of interest is coefficient of friction, and a lower value means less friction and a faster ski. For example, if it's 10 degrees F and there's new snow, CH8 has a friction coefficient of about 0.025, and the other waxes all have about the same friction coefficient value of 0.0225. This means that CH8 would be slower, no surprise, given the temperature. What might be surprising to some is that on average, CH4, CH6, and Rex Blue all have the same performance at 10 degrees F.

In another example, let's say the snow is several days old, and the temperature is 25 degrees F. In that case, CH8 has the lowest friction, at 0.0125, Rex Blue and CH6 are similar at 0.015, and CH4 has the highest friction, about 0.0175. Even though CH4 is the slowest of the four waxes at 25 degrees F(just like the package tells you), it is still faster than anything we measured on new snow at 10 degrees F. One of the things we learned is that the weather usually matters more than the wax!

In general, temperature behavior corresponds with the recommendations from Swix and Rex for the rank order. However, you might be still wondering what this all means for race times. Recall previously that there are only four things that affect ski speed: skier propulsion, gravity, air drag, and ski/snow friction. Now that we know the coefficient of friction we can use that information in a computer model that takes into account how much power a person can expend while skiing, and balance that with how much friction the ski has at a given temperature, how much aerodynamic drag there is at a given speed, and the ski course elevation profile. The effect of friction will generally result in a change of about 2 seconds per kilometer for every 0.001 change in coefficient of friction.

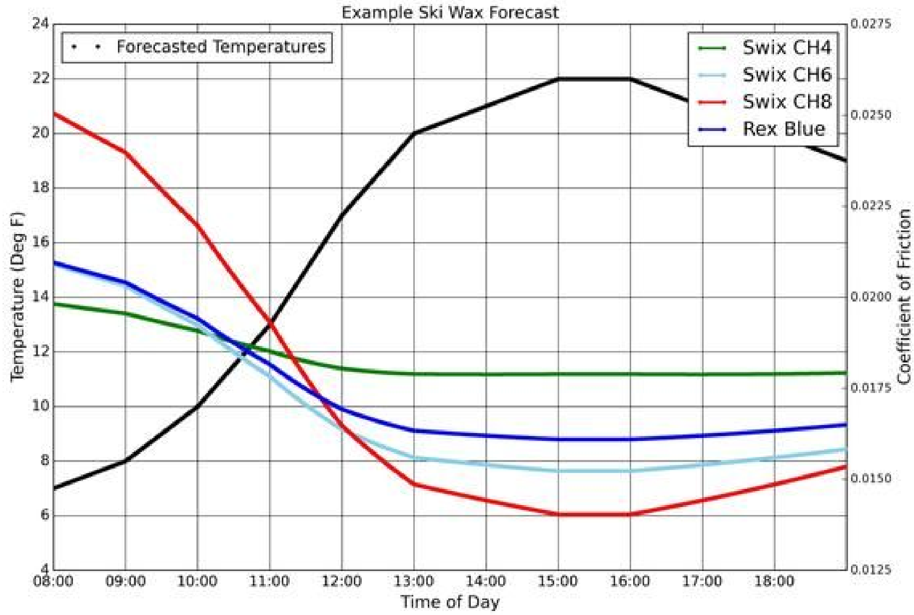
For a practical example, let's use the elevation profile of the 2016 American Birkebeiner alongside some published values for skier propulsion and air drag. For a consistent temperature of 10 degrees, a Wave 2 skier with CH8 could be expected to complete the race in 3:12. If that same skier would have used Rex Blue, or CH4, or CH6, they would have completed the race in 3:07. A five minute difference.

Of course the temperature rarely stays at a constant value during a race. We ran that model for the Birkie course with a typical temperature forecast: 7 degrees Fahrenheit at 8:00 AM, and 22 degrees at 3:00 PM.

The chart below shows the following:

1. The black line shows the air temperature as a function of the time of day. The temperatures are shown on the scale on the left.

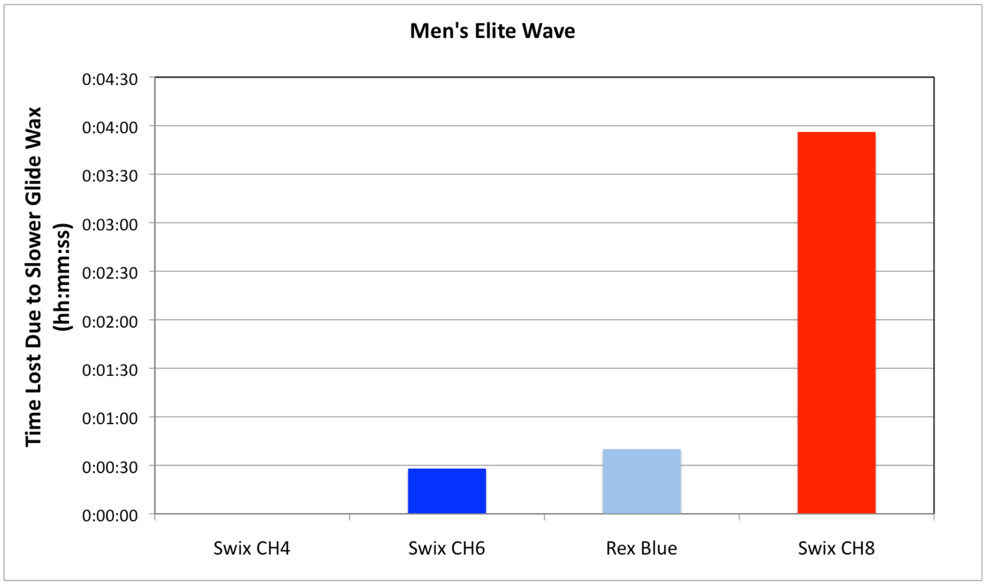
2. The other colored lines show the coefficient of friction that the different waxes would have at that time of day at that temperature. The friction is shown on the scale on the right.



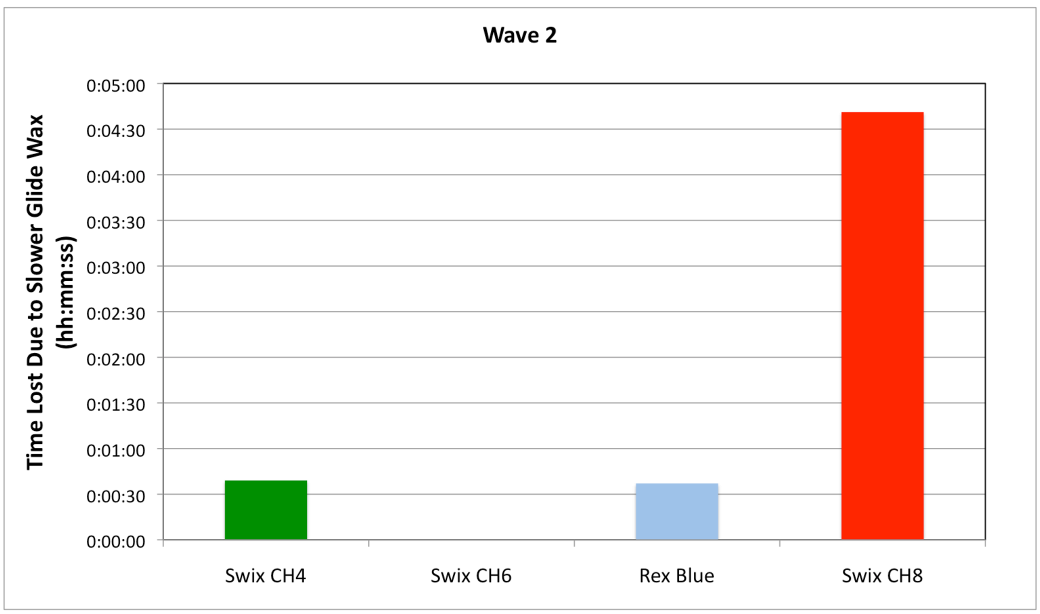
On this chart the fastest wax at any particular time of day is the one with the lowest coefficient of friction. Early in the day CH4 is fastest but after noon the fastest would be CH8. What would be the fastest wax over the course of the races? We can figure that out!

We know what time of day the various Birkie waves start, and we know approximately how much power the average skier in each wave can expend, so we can combine all this info in our computer model and estimate the difference in finishing times using these different waxes. The charts below show some of the results.

If you start early in the morning in the Men's Elite Wave and finish with an 'average' time for an elite wave skier, the best wax for you would be CH4. Had you used CH6 your finishing time would have been about 30 seconds slower, and if you used CH8 you would have been about 4 minutes slower.



But if you had started a bit later in the morning in Wave 2 with warmer conditions and finished with an average Wave 2 time, your best wax would be CH6, with CH4 now being about 30 seconds slower.



The results for each wave, in table form, are shown in the chart below. The best wax for each wave is shown in bold font. The table shows the time lost had you used a wax other than the best wax.

	Swix CH4	Swix CH6	Rex Blue	Swix CH8
Women's Elite	**0:00:00**	0:00:47	0:01:01	0:06:06
Men's Elite Wave	**0:00:00**	0:00:28	0:00:40	0:03:56
Wave 1	0:00:01	**0:00:00**	0:00:27	0:04:54
Wave 2	0:00:39	**0:00:00**	0:00:37	0:04:41
Wave 3	0:01:51	**0:00:00**	0:00:56	0:03:58
Wave 4	0:03:06	**0:00:00**	0:01:17	0:03:28
Wave 5	0:04:52	**0:00:00**	0:01:50	0:02:41
Wave 6	0:07:23	**0:00:00**	0:02:38	0:01:22
Wave 7	0:11:08	0:00:06	0:03:13	**0:00:00**
Wave 8	0:16:17	0:02:38	0:06:38	**0:00:00**
Wave 9	0:16:26	0:04:36	0:07:16	**0:00:00**

We plan to run this model before all the major events in the Midwest using the weather forecast for that day and post the data on our website.

It took us a long time but we did achieve our goal. We now have a pretty good estimate of just how much difference there is between the waxes and what it means for performance. It's an ongoing effort with more waxes being tested. Another big question on our minds is, "How much better are those fluorinated waxes?". Stay tuned . . . .

If you'd like to participate, or have more questions, contact the authors at: (rickbudde@me.com or adam.k.himes@gmail.com).