Purchased by the Forest Products Laboratory,
U. S. DeparGunstocks1griculture, for official use.

NEW CHEMICAL TREATMENT CURBS

Shrink and Swell of Walnut Gunstocks[1]

H. L. MITCHELL AND H. E. WAHLGREN
Forest Products Laboratory,' Forest Service U. S. Department of Agriculture

Reduces shrinkage and swelling to less than thermal expansion of most plastics . . . Practically eliminates splits, checks, and other seasoning degrade . . . Reduces kiln time by about two weeks . . . Advantages for the rifleman—dimensional stability plus warmth and beauty of wood.

Basing their work on fundamental research by Dr. A. J. Stamm, the authors, H. L. Mitchell (seated) and H. E. Wahlgren, carried this program through research, laboratory, and pilot plant stages in less than 10 months. The work has been picked up by industry, and the stabilized gunstocks are being produced commercially.

A NEW CHEMICAL TREATMENT that imparts a high degree of dimensional stability to solid wood gunstocks has been developed by the U. S. Forest Products Laboratory. Rifle stocks machined from green walnut and treated with the chemical before they are kiln dried will, when seasoned, shrink and swell substantially less than untreated "control" stocks. Such chemically stabilized stocks are not apt to change sufficiently in dimension to throw a well-bedded barrel and action out of alinement, even when the rifle is exposed to extremes of temperature and humidity.

For best results, the chemical must be applied to the green wood fresh from the saw. Treatment of precarved stocks or stock blanks at this stage practically eliminates splits, checks, internal honeycomb, and other degrade during seasoning, and permits accelerated drying according to a kiln schedule far more drastic than that normally recommended for walnut gunstock blanks. Or, the treated wood can be air dried over a longer period with equally good results. Preliminary studies indicate that even highly figured woods like Oregon myrtle, curly bird's-eye maple, and some wild-grain tropical species—all known to be bad actors from the standpoint of tendency to split, check, and warp during drying—can be seasoned without significant degrade with this process.

The chemical used is polyethylene glycol-1000. The "1000" refers to the average molecular weight of this compound. It is a first cousin of permanent-type antifreeze, and is a member of a whole family of polyethylene glycols having varying molecular weights, solubilities, freezing and boiling points, and other properties. Polyethylene glycol-1000 is a white, waxlike chemical that resembles paraffin. It dissolves readily in warm water, is nontoxic, noncorrosive, melts at 104° F., and has a very high (580° F.) fire point.

Drdimensional , formerly on the staff of the Forest Pr(9):ucts Laboratory, and now with North Carolina State College, pioneered the use of polyethylene glycols to restrain wood from shrinking and swelling.[3] He assisted in planning, and helped to start the work on gunstocks here described. Dr. Stamm's fundamental research in the

The Authors: Harold Mitchell is Chief of the Forest Products Laboratory's Division of Timber Growth and Utilization Relations; H. E. Wahlgren is a research technologist at the Laboratory.

[1] A contributed paper received October 1959.
[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Stamm, A. J. 1959. Effect of polyethylene glycol on the dimensional stability of wood. For. Prod. Jour. IX (9): 375-381.

Reprinted from the December, 1959, Forest Products Journal (Vol. IX, No. 12), pages 437-441
Forest Products Research Society, 417 North Walnut Street, Madison 5, Wisconsin

Stock and forearm blanks end coated, chemically treated, and kiln dried on accelerated schedule; and finished products fitted to Remington Model 11.

field of dimensional stabilization of wood has been widely published in various technical journals and reports. Processes based on his work are now used commercially, on a limited basis, in the manufacture of wood carvings, and in related industries.

Polyethylene glycol affects dimensional stability of wood by diffusing into and lodging in the fine structure of the fiber walls, where it provides a bulking action that restrains the walls from shrinking as they dry. For example, when a piece of wood is completely saturated with a 30 per cent aqueous solution of polyethylene glycol-1000, it does not shrink to appreciably less than its green dimensions even when air seasoned at low humidities for a long period, followed by oven-drying at 212° F. to a moisture-free condition. Neither will it swell appreciably when exposed to high humidities. By way of comparison, untreated walnut shrinks in volume an average of 12.8 per cent when taken from the green to the bone-dry condition. Under the same conditions, even-textured, straight-grained black cherry shrinks 11.5 per cent and hard maple 14.9 per cent. Highly figured woods, because of interlocked grain or other fiber distortions and abnormalities, normally shrink and swell even more than straight-grained specimens of the same species, and therefore have a greater tendency to warp, twist, and split during seasoning.

Description of Experiments

In the studies here reported, two fresh-cut walnut logs from a farm woodlot in the vicinity of Richland Center, Wis., were sawed into 2-1/2-inch-thick planks at the Dunston and Merry Mill at Richland Center. Immediately following sawing, the planks were transported to the Forest Products Laboratory, where 28 standard-size shotgun stock blanks were band sawn from them. The stock blanks, from carefully matched planks, were then divided into two groups.

Half of the green shotgun stock blanks were sealed in polyethylene bags, to prevent moisture loss, and stored in a conditioning room maintained at a constant 35° F and 82 percent relative humidity.

The other half of the green blanks were soaked for 39 days in a vat containing a 30 percent (by weight) aqueous solution of polyethylene glycol-1000 maintained at room temperature that averaged about 73° F. The chemical used was supplied by The Dow Chemical Company, Midland, Mich. Henry A. Huber of Dow's Technical Service and Development Department assisted in planning these and subsequent experiments.

Several control specimens of green walnut 2 by 2 by 8 inches in size were put in the soaking vat along with the gunstock blanks. These controls were used to check depth of penetration and amount of polyethylene glycol taken up by the blanks. About once a week, one of these specimens was removed from the vat, and a thin section was sawed out from near the center for quantitative analysis by a vacuum extraction method. Our objective was to get enough chemical into the wood to achieve marked improvement in dimensional stability in an economically feasible period of soak.

In another phase of the same experiment, eight standard-size rifle blanks were cut from the matched planks, sealed in polyethlene bags, and transported to the plant of the cooperating gunstock manufacturer, the Win—A-Mer Company, Waseca, Minn. There they were inletted for a Springfield action and machined to the Win—A-Mer custom sporter pattern to within approximately 1/8 inch of the desired finished dimensions. Then they were soaked in a 30 per cent polyethylene glycol-1000 solution for 24 days.

The precarved stocks are much smaller in diameter than the blanks, and inletting for action, barrel groove, and magazine box permits diffusion of the chemical into the wood from two sides. Therefore, it is possible to get sufficient chemical into the wood to achieve a high degree of dimensional stability, especially in critical areas, in a shorter period of soak than is required for the thicker blanks.

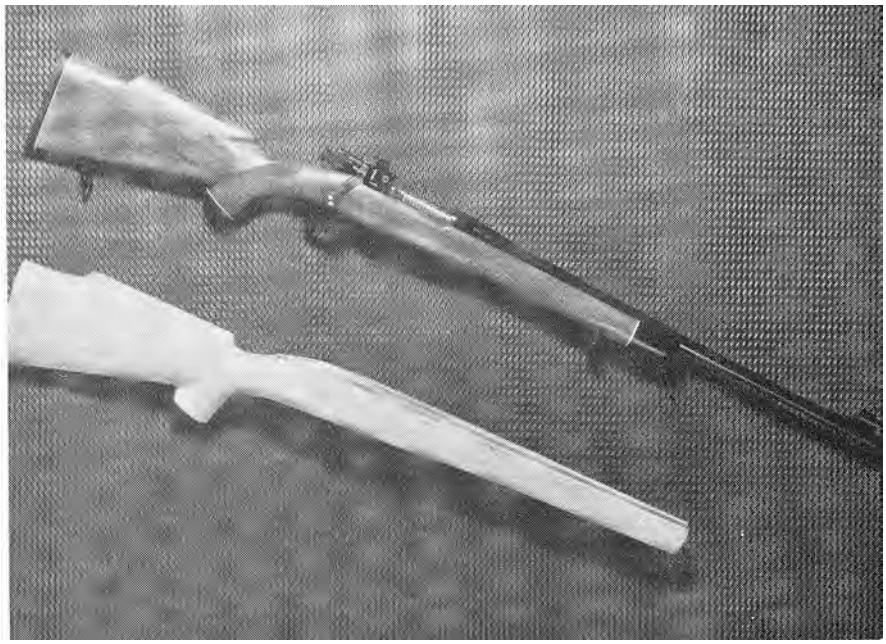
At the end of the soaking period, the chemically treated blanks and precarved stocks, together with the untreated blanks from cold storage, were accurately measured with a micrometer at several marked spots, and their green dimensions recorded. The treated and untreated blanks, and the treated precarved stocks, were then divided into two equal groups and placed in separate experimental dry kilns.

One kiln was operated according to the schedule normally used for drying

walnut gunstock blanks. This schedule was developed by the Forest Products Laboratory during World War II at the request of the Army for use in drying stocks for military small arms. It is described in detail in Forest Products Laboratory Report No. R1433. With this schedule, it took 57 days to reduce the moisture content of the blanks and precarved stocks from the green condition to an average moisture content of 6 percent, including 5 days at the end of the kiln run for equalizing and conditioning.

The other kiln was operated according to a schedule far more drastic than any heretofore recommended for commercial use. With this schedule, the moisture content of the green blanks and precarved stocks was reduced to 6 percent in only 44 days-13 days less than the normal kiln time for this sort of material.

At the end of the kiln runs, all blanks and precarved stocks were again micrometered at the same points at which their dimensions were measured in the green condition.



Precarved (from green wood), chemically treated, kiln-dried walnut stocks, one finished and fitted to sporterized Springfield M1903A3 and the other as it appeared when taken from the kiln. (Stock by Win-A-Mer Co., Waseca, Minn.; metal work by Rusk Gun Shop, Madison, Wis.)

Effect on Seasoning Degrade

All of the chemically treated precarved stocks came out of the kilns in excellent condition. There was no sign of surface checks, splits, or other defects, even on those dried according to the drastic schedule. About half of the stocks were sawed across the thick part of the butt midway between the toe and the pistol grip to check for internal honeycomb. No such defects were found. These findings are especially significant in view of the fact that the precarved stocks were not even given the usual end coating (a mixture of asphalt and coal-tar pitch) before they went into the kiln.

The results of these and later studies show that thick walnut blanks treated with polyethylene glycol can also be successfully dried by the drastic schedule used. However, with the thick blanks, which take longer to reach the same level of chemical treatment as the smaller precarved stocks, it is necessary to apply the usual end coating previous to chemical treatment and subsequent drying. End coating retards drying and also prevents development of a severe stress gradient between the heavily treated end grain and the interior fibers, which contain little or no polyethylene glycol, thus controlling the internal honeycomb that may otherwise develop.

As anticipated, the drastic kiln schedule proved too severe for the end-coated blanks that received no chemical treatment. Most of these blanks showed surface checks and splits as well as internal honeycomb. In contrast, the untreated, end-coated blanks that were dried according to the normal schedule, which is widely used commercially, came through in good condition.

Effect on Shrinkage During Kiln Drying

The data summarized in Table 1 show that soaking in polyethylene glycol solution reduced shrinkage of the treated stock blanks to from one-half to one-sixth of that of comparable untreated blanks The variation within treatments noted in the table is due largely to the fact that some of the blanks were from quarter-sawn planks, some from flat-sawn planks, and some from planks varying somewhere between flat and quarter sawn. In all wood, shrinkage and swelling are greatest tangential to the annual growth rings (flat sawn), somewhat less radially (quarter sawn), and least of all longitudinally.

Shrinkage and Swelling of Critical Areas of Finished Stocks Can Be Virtually Eliminated

The data summarized in Table 2 show how chemically stabilized rifle stocks compare with untreated ones in shrinkage and swelling when exposed to extremes of relative humidity. In this experiment, the seasoned stocks were subjected to conditions that are more severe, in range and duration, than those likely to be encountered in normal use.

The chemically treated precarved rifle stocks and an equal number of untreated stocks shaped and inletted in the usual manner from kiln-dried blanks, were first placed in a conditioning room maintained at a constant 80° F. and 30 percent relative humidity. They were weighed weekly until they showed no significant change in weight, indicating that they had attained equilibrium moisture content for this temperature and humidity. Their dimensions were then carefully measured at several points with a micrometer, after which they were all transferred to another conditioning room maintained at a constant 80° F. and 90 percent relative humidity.

In a little over 5 weeks, the stocks had absorbed sufficient water vapor to reach equilibrium moisture content for the 90 percent humidity environment. They were again micrometered, and their expansion was expressed as a percentage of their dry dimension in the 30 percent humidity environment. These are the data summarized in Table 2. When the stocks were again placed in the low-humidity room they lost the moisture they picked up in the 90 percent humidity environment, and they shrank back to approximately their former dimensions.

The swelling that resulted from cycling the stocks between the low- and high-humidity environments was less (from 2.6 to 3.6 percent for the un-

Technologist inspects precarved stocks following chemical treatment and before kiln drying.

Technologist using micrometer to obtain precise measurement.

Precision balance was used to weigh stocks at various stages during processing.

treated stocks) than the shrinkage (Table 1) of the walnut blanks from the green to the kiln-dry condition. This is because the chemical and physical changes that take place during the drying process are such that seasoned wood can never again swell to its original green dimensions, regardless of how long it is exposed to high humidities. However, the shrinkage and swelling that occur in even such relatively stable woods as walnut, mahogany, and cherry under normal use conditions are sufficient to cause trouble for certain demanding uses, including stocks for highly accurate rifles.

As shown by the data in Table 2, the polyethylene glycol treatment greatly reduced the shrinkage and swelling that normally accompany exposure to extremes of relative humidity. Most significant is the reduction across the forearm in the area of the barrel groove and action. Shrinkage and swelling in this critical area is reduced to 1 percent—only a little over one-fourth that of untreated stocks. It can be considered as negligible for the range and duration of humidity conditions to which most rifles are exposed in normal use. This is especially true in view of the fact that most finished stocks are coated with a varnish or resin-base sealer that retards, but does not prevent, moisture movement into and out of the wood.

For the purists who wish to go all the way, shrinkage and swelling in the critical areas can be virtually eliminated by increasing the period of soak. Dr. Stamm's earlier work shows that when the amount of chemical diffused into the wood reaches 30 percent of the dry weight of the wood, normal shrinkage and swelling at the very extremes of relative humidity are reduced by more than 82 percent. Fortunately, penetration of the chemical is greatest in the vicinity of the barrel groove and action, where a high degree of dimensional stability is most important. Here the wood is relatively thin, and the chemical diffuses into it from two sides.

It has been assumed by some that bedding the barrel and action in "glass" (a commonly used generic term applied to various plastics) will keep barrel, action, and stock in perfect alignment. Although glass bedding has some desirable features, it is not the answer to this particular problem. The glass is bonded to and supported by the wood of the stock. When the stock shrinks and swells with variations in relative humidity, so does the plastic. The forces exerted by swelling wood are tremendous, and no relatively thin layer of plastic, regardless of its inherent strength, can have a significant restraining effect on normal shrinkage or swelling of the supporting wood. The chief advantages of glass bedding are that it enables an amateur to do an acceptable job of bedding, and that the plastic does significantly increase strength in critical areas around the recoil lug and rear tang.

Another common misconception is that wood will not shrink or swell appreciably after kiln drying. This, of course, is not true, as the data in Table 2 clearly show. An equally erroneous assumption is that the commonly used stock finishes—varnishes, resin-base sealers, lacquers, linseed oil, etc.—prevent the movement of water vapor into and out of the stocks with changes in relative humidity, and thus prevent shrinkage and swelling. Nothing could be further from the truth. No finish known will *prevent* the movement of water vapor into and out of wood. Even the best merely slow up the process. Linseed oil and other oil-base finishes, although they have some desirable properties, are especially ineffective in slowing up water absorption and loss.

Effect of Chemical Treatment on Strength, Gluing, Finishing, Resistance to Rot, and Weight

A comprehensive series of experiments by Dr. Stamm on matched specimens of treated and untreated wood showed that polyethylene glycol-1000 has no effect upon the toughness of wood. It reduces the modulus of rupture, modulus of elasticity, and abrasion resistance of wood only slightly, and by about the amount that would be expected from the reduction in shrinkage. The effect of the stabilizing chemical on strength is not considered to be of any practical significance.

Wood specimens treated with polyethylene glycol were successfully bonded together with a wide variety of common glues. Strength of the glued joints was determined by measuring the tensile load required to break the glued specimens. Casein, cold-setting urea, and hot-setting phenolic glues gave the highest readings for tensile strength.

None of the common gunstock finishes tested dried well over wood treated with polyethylene glycol, and adhesion and durability were generally poor. Only a new polyurethane resin-base finish proved entirely satisfactory from all standpoints. It dried rapidly and gave a beautiful, tough, durable, water-resistant finish.

Table 1.--Average shrinkage of chemically treated and untreated walnut shotgun blanks dried from the green to the kiln-dry condition according to two drying schedules

Treatment	Shrinkage, based on dry dimension			
	Normal kiln schedule		Drastic kiln schedule	
	Width	Thickness	Width	Thickness
	Percent	Percent	Percent	Percent
Polyethylene glycol-1000[1]				
Average	2.6	2.1	2.0	1.2
Range	1.7-3.3	1.7-2.7	1.1-2.6	0.4-2.3
Untreated				
Average	4.4	7.1	8.8	7.4
Range	2.1-5.9	5.8-10.9	3.8-12.9	4.2-10.3

[1] Soaked 39 days in 30 percent (by weight) solution of polyethylene glycol-1000.

Table 2.--Dimensional changes in treated and untreated rifle stocks exposed to extremes of relative humidity[1]

Treatment	Expansion, based on dry dimension		
	Butt, from heel to toe	Butt thickness, midway between heel and toe	Across forearm
	Percent	Percent	Percent
Polyethylene glycol-1000[2]	1.8	2.2	1.0
Untreated[3]	2.6	3.6	3.6

[1] Cycled between two conditioning rooms maintained at constant conditions as follows: (1) 80° F., 30 percent relative humidity; (2) 80° F., 90 percent relative humidity.

[2] Green, precarved stocks soaked 24 days in 30 percent (by weight) solution of polyethylene glycol-1000, then kiln dried.

[3] Stocks shaped and inletted in usual manner from untreated kiln-dried blanks.

Treated specimens of wood were subjected to the standard ASTM soil-block culture test for 3 months after inoculation with fungi. The results of these tests show that treatment with polyethylene glycol-1000 increased the resistance of the wood to decay.

The amount of polyethlene glycol absorbed by a precarved stock during treatment does not result in an appreciable increase in the weight of the finished stock. One reason is that there is relatively little chemical in the thick part of the butt, where a high level of stability is unimportant. Moreover, the weight of the added chemical is largely offset by what amounts to a reduction in the density of the seasoned wood. Since chemical treatment restrains normal shrinkage during drying, the weight of wood substance in a stabilized stock is less, per unit of kiln-dry volume, than in an untreated stock that shrinks normally during the drying process.

Limitations of Treatment

The cost of the chemical itself is not excessive when purchased in minimum commercially available quantities of 500 pounds or more. However, the relatively long period required for chemical treatment-24 or more days for precarved stocks and 39 days for blanks—may tend to limit commercial application, especially in the processing of blanks. In this connection, it should be pointed out that research in progress shows promise of developing more efficient means of getting the chemical into the wood. Now under test are elevated temperatures in the soaking vats and a series of short-period dips in pure molten polyethylene glycol followed by conditioning in warm, moist environments. It is hoped that these techniques may speed up diffusion of the chemical into the wood fibers, and thus reduce the time required for treatment of both precarved stocks and thick blanks.

Another disadvantage, but one easily overcome, is that polyethylene glycol is readily soluble in water. Over a long period of time it would tend to leach out in substantial amounts with exposure to rain and an occasional accidental dunking in some mountain stream. Several coats of the polyurethane resin-base finish, mentioned previously, will prevent such leaching. It should, of course, be applied to the barrel groove and the inletted areas around the action and magazine box, as well as to visible parts of the stock. Although the polyurethane finish, like all others, is somewhat permeable to water, it forms a protective membrane that is practically impervious to the large molecules of polyethylene glycol-1000. Test specimens that had been treated with polyethylene glycol and then coated with the polyurethane finish lost practically none of the stabilizing agent even after complete immersion in running water for 2 weeks. Moreover, the finish showed no sign of blistering or other deterioration.

To be fully effective, the polyethylene glycol treatment must be applied to green wood fresh from the saw. It is not recommended for use on lumber or blanks that have been exposed to drying conditions for even a few days, and cetrainly not for air-dried or kiln-dried blanks or finished stocks.

Advantages

The greatest single advantage of the polyethylene glycol treatment, from the standpoint of the rifleman, is the high degree of dimensional stability attainable in critical areas of precarved stocks. Shrinkage and swelling can be reduced to a negligible amount—substantially less than the thermal expansion of most plastics.

Precarving itself has certain distinct advantages : Green wood can be shaped, sawed, and inletted more easily than seasoned wood, and does not dull cutting tools as rapidly. Moreover, the dust problem around the milling machines and duplicators is largely eliminated.

Chemical treatment of the precarved stocks practically eliminates splits, checks, and other degrade during seasoning, and permits kiln drying on an accelerated schedule that reduces drying time by about 2 weeks. Or the treated precarved stocks can be air dried over a longer period with equally good results.

Even when thoroughly seasoned, wood treated with polyethylene glycol works more easily than equally dry untreated wood. According to Ike Wynnemer, owner of the Win—A—Mer Company, "this chemically stabilized wood certainly cuts, carves, and shapes better than any wood I have worked with in my 20 years of stock making. It's a pleasure to fit a barrel and action to one of these stocks." One reason for this is that bulking the wood fibers with polyethylene glycol is somewhat comparable to the common laboratory technique of embedding plant and animal tissue in paraffin to provide support and otherwise facilitatehumidity1ing of thin sections for microscopic examination.

It is believed that chemically stabilized stocks will out-perform any substitute material thus far developed and at the same time retain the natural warmth, beauty, durability, and other desirable properties of the fine hardwoods long prized by American sportsmen.

The polyethylene glycol treatment is also effective in preventing seasoning degrade of glycol-10002tock blanks. Thick walnut blanks that are end coated and then trea d with the chemical can be kiln dried on an aclerated schedule without appreciable d1Cycled or air seasoned over a longer period with equally good results. Stocks made from the treated blanks do not have the high degree of dimensional stability found inreen precarved stocks because the outside areas containing most of the chemical are cut away during machining to the finished dimensions. Here the objective is simply to get enough chemical into the 3Stockslanks to prevent seasoning degrade and to permit faster kiln drying.